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# Seam Characteristics of Breathable Waterproof Fabrics with Various Finishing Methods

**Won Young Jeong and Seung Kook An***

*Dept. of Textile Engineering, Pusan National University, Busan 609-735, Korea*

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**Abstract:** We evaluated the seam characteristics with finishing, seaming and sealing processes and seam puckering behavior of the breathable waterproof fabrics with laser scan. There were differences in 99 % significant level between the seamed fabric and the sealed fabric. Seam breakage was initiated with the breakage of sewing thread, so the seam strength after seaming was almost uniform. The sewn seam strength and elongation increased with sealing process in all finishing methods. Pucker grade of laminating type was generally much higher than that of the coating type. We confirmed that wave length and amplitude have more important meaning than the number of wave in the breathable waterproof fabrics. The puckering in breathable waterproof fabrics is mainly occurred by inherent and feeding pucker. The former is due to the insertion of sewing thread and the latter is caused by differential feeding when two pieces of fabric are fed into the gap between a press foot and needle plate.

**Keywords:** Seam characteristics, Seam sealing, Seam pucker, Shape parameters, Breathable waterproof fabric

## Introduction

The main task of the garment manufacturer is to produce shell structures out of flat fabrics to match the shape of the human body. The most acceptable means of joining textile materials for apparel use is by sewing. The tailoring operations influence not only garment appearance but also clothing comfort, so the mechanical properties of the seamed fabrics are as important as those of the finished fabrics prior to tailoring[1,2]. Most of the breathable waterproof finishing is carried out on fabric substrates, and the combinations of the materials have the advanced properties, but various physical properties are significantly changed after finishing, seaming, and sealing processes. In case of breathable waterproof fabrics, the seamed fabrics are sealed by waterproof sealing tape to prevent water from penetrating through the holes caused by stitching of needle.

In subjective evaluation for seam pucker, most of them were developed to provide substitute devices for human eye by the American Association of Textile Chemists and Colorists (AATCC) standard 88B method. However, problems do arise when judges disagree on the ranking of the sewn fabric strips, and thus the quality and specification standards are difficult to implement due to subjectivity and the time involved in the ranking procedure. For several decades, many methods for evaluation of seam pucker have been reported using new technology[3-5]. A number of new attempts were made in which CCD cameras[6,7] or laser scanners[8-10] were used to capture the image of a seam, and artificial intelligence was applied to establish the relationship between the objectively measured parameters and subjective grades.

In this study, we evaluated the seam characteristics with finishing, seaming and sealing processes and seam puckering behavior of the breathable waterproof fabrics with laser scan. The significant changes of tailoring properties were analyzed and compared with different breathable waterproof finishing.

*Corresponding author: ansk@pusan.ac.kr

## Experimental

### Materials

Twenty-two breathable waterproof fabrics commercially used to sports wears and foul weather garments were chosen. Table 1 shows the classification and the characteristics of the materials used in this study. The specimens were prepared by polyurethane direct coating and PTFE (Polytetrafluoroethylene) membrane laminating methods. The coated fabrics with polyurethane were obtained by microporous structure through wet- or dry-coagulation process except A type in dry coating. The laminated specimens used in this study were supplied from W. L. Gore & Associates, Inc. and these were prepared through laminating process with PTFE membrane. They were composed with base fabric, PTFE membrane, and knitted lining, and these materials combined through adhesives sprayed between the base fabric and the PTFE membrane. The functional component of these laminates was a same microporous membrane made from solid PTFE sheet. The unfinished fabrics were also used for comparison with the finished ones in this study.

### Seaming and Sealing Condition

The seaming was performed on standard sewing machine, and the details of the sewing conditions are shown in Table 2. All seams were sewn at constant machine conditions, and 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[11]. By using this machine the samples

**Table 1.** Specifications of the breathable waterproof fabrics

| Code | Description of finishing methods | | | Construction of base fabric | | |
|---|---|---|---|---|---|---|
| | Finishing methods | | Functional component | Fiber contents | Thickness (mm) | Weight (mg/cm$^2$) |
| WA1 | wet coating | floating knife | polyurethane | nylon | 0.28 | 8.36 |
| WA2 | | | | nylon | 0.14 | 6.69 |
| WA3 | | | | nylon | 0.54 | 16.68 |
| WB1 | wet coating | roll over knife | polyurethane | nylon | 0.32 | 11.91 |
| WB2 | | | | nylon | 0.52 | 12.45 |
| WB3 | | | | nylon | 0.41 | 10.58 |
| WB4 | | | | nylon | 0.19 | 9.82 |
| DA1 | dry coating | floating knife | polyurethane | nylon | 0.29 | 8.94 |
| DA2 | | | | nylon | 0.52 | 12.45 |
| DA3 | | | | nylon | 0.63 | 17.30 |
| DB1 | dry coating | roll over knife | polyurethane | nylon | 0.53 | 10.80 |
| DB2 | | | | nylon | 0.53 | 13.43 |
| DB3 | | | | nylon | 0.25 | 9.69 |
| DB4 | | | | nylon | 0.63 | 17.30 |
| 2L1 | laminating | 2-layer | PTFE membrane | nylon | 0.24 | 11.10 |
| 2L2 | | | | nylon | 0.34 | 12.81 |
| 2L3 | | | | nylon | 0.37 | 16.43 |
| 2L4 | | | | nylon | 0.41 | 17.47 |
| 3L1 | laminating | 3-layer | PTFE membrane | nylon | 0.48 | 17.06 |
| 3L2 | | | | nylon | 0.47 | 16.81 |
| 3L3 | | | | nylon | 0.51 | 18.96 |
| 3L4 | | | | nylon | 0.42 | 17.95 |

**Table 2.** 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.

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 temperature and feeding speed were controlled with the characteristics of the specimen.

### Characteristics of the Seam

Measurement of the seam strength and elongation were carried out on a constant-rate-of-extension (CRE) type of machine capable of jaw separation rate of 305±10 mm/min in accordance with ASTM D 1683. The breaking force required to effect rupture of sewn seams is measured using the grab test procedure in test method of ASTM D 1682. During application of the force to the sewn seam specimen, the seam rupture was observed and recorded whether it was caused by (1) yarn rupture in fabric, (2) sewing thread rupture, and (3) sewn seam yarn slippage.

### The Judgment of Seam Pucker Grade

We measured seam pucker of fabrics with laser scanner (KD03, D&M Technology, Korea), which the new standards are used with the shape parameters. The new standards of seam pucker are defined using five shape parameters such as the number of random points related to wave generation, the wave amplitude at seam line, the wave length at seam line, the wave amplitude at edge line, and the wave length at edge line[12]. The shape parameters and AATCC grade were calculated with the new standards.

## Results and Discussion

### Seam Characteristics of Breathable Waterproof Fabrics

Tailorability is closely connected to the quality of final product. The tailorability after sewing process is evaluated with seam puckering related to seam appearance and seam strength is connected to seam characteristics. The seam strength is the force at seam breakage, which is affected by the material for seaming and sewing technology. In this study, seam characteristics with breathable waterproof finishings

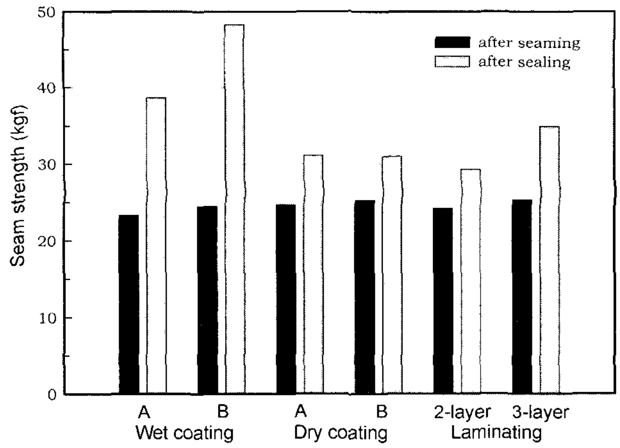


**Figure 1.** Sewn seam strength with seaming and sealing processes of breathable waterproof fabrics.

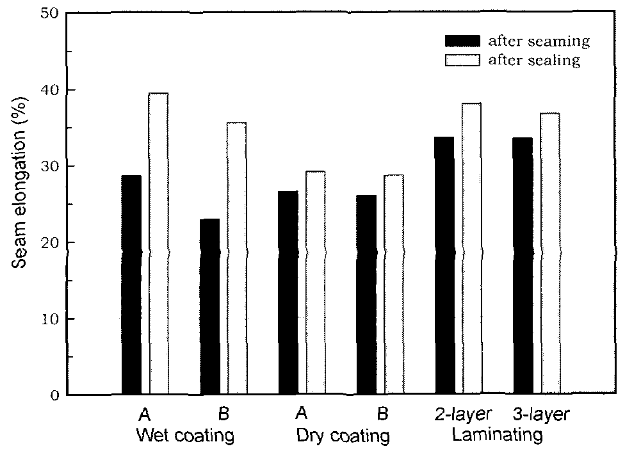


**Figure 2.** Sewn seam elongation with seaming and sealing processes of breathable waterproof fabrics.

were quantitatively tested on the fixed sewing condition.

The waterproofness of seams is the weakest in locations where seams intersect, and where several pieces join other thickness of material, as in pocket flaps and neck seams. Special care and provision for welding are made in these areas. Equally the performance of seams must be maintained during flexing, appropriate washing and dry cleaning, and exposure in use.

Figures 1 and 2 show mean values of seam strength and seam elongation with finishings. In all cases, the seam strength and the seam elongation increased with sealing process. It meant that sealing process played an important role in resistant to seam strength. Seam slippage was not found to seam breakage in all cases. Seam breakage was initiated with the breakage of sewing thread at seam line on seamed fabric. In Figure 1, the seam strength after seaming is almost uniform, namely, we can predict the seam strength with the strength of sewing thread. The adhesive force between sealing tape and fabric affects on the seam strength after sealing.

The seam elongation after seaming was influenced by sewn thread characteristics as well as the frictional force between sewing thread and the outer wall of the stitch hole. For these frictional forces, there were some differences among the values of finishing methods. In all cases, there were differences in 99 % significant level between the seamed fabric and the sealed fabric. Therefore, it is necessary to analyze the variation of seam characteristics with sealing to evaluate a breathable waterproof fabric.

## Seam Puckering Behavior with Breathable Waterproof Finishings

AATCC method has generally been used to evaluate seam puckering. Each seamed sample is graded with the naked eyes as compared with the standard photographs. But, this method has a trouble of deviation between operators. Some researchers have studied to evaluate the seam puckering using a Moir, laser, ultrasonic or a CCD camera for objective grading. A simulator was developed to construct the artificially intelligent machine for evaluating seam pucker[12], and the objective system was used to evaluate the seam pucker of breathable waterproof fabrics in this study. On the system, the puckered shape is converted into numerical data on a three-dimensional coordinates by the developed laser measurement system and five shape parameters can be obtained by the pattern recognition of neurofuzzy engine and defuzzification process.

In this study, objective seam pucker test was performed for various finished specimens. The obtained data were treated with noise filtering, and Table 3 shows the mean values of shape parameters with various breathable waterproof finishings. The results of the laminating type generally showed lower wave amplitude at seam line and edge line than those of the coating type. But, its wave lengths at seam line and edge line were much longer than those of the coating type. The amplitude and the wave length at edge line were twice as large as those at seam line. The waves are generated on the seam line, and propagated to the edge line in the perpendicular direction to the seam line. Compared with actual clothing, the sample used in this study was so narrow, of which size was 100 mm in width. It could be more severe on the wave length and amplitude in actual clothing.

Figure 3 shows the trend of AATCC seam puckering grade with finishing methods, and Figure 4 shows the real puckering photographs. As mentioned above, the grade of laminating type was generally much higher than that of the coating type, that is, the laminating type showed the lower pucker. Figures 5-9 show the relationship between the evaluated shape parameters by the system and AATCC grade. AATCC grade decreased with high correlativity with the wave amplitude, while the wave length increased with correlation coefficient of $r^2 = 0.87$ and $r^2 = 0.76$. However, the correlation coefficient

**Table 3.** Shape parameters with breathable waterproof finishings by converted neurofuzzy engine

| Finishing method | Start amplitude (mm) | End amplitude (mm) | Start wave length (mm) | End wave length (mm) | No. of random point |
|---|---|---|---|---|---|
| Wet coating A | 4.00 | 8.19 | 38.23 | 79.76 | 3.13 |
| Wet coating B | 4.00 | 9.42 | 34.13 | 53.48 | 4.94 |
| Dry coating A | 4.00 | 9.79 | 40.86 | 76.02 | 4.39 |
| Dry coating B | 4.00 | 8.25 | 33.93 | 56.48 | 3.00 |
| 2 Layer laminating | 3.76 | 7.22 | 45.40 | 95.65 | 2.97 |
| 3 Layer laminating | 3.39 | 5.35 | 57.69 | 104.93 | 2.62 |

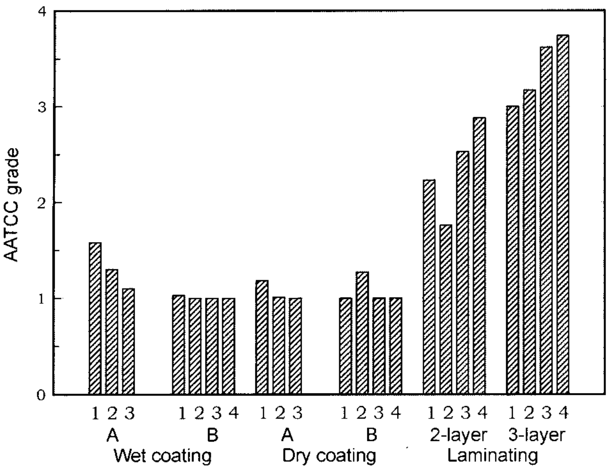


**Figure 3.** AATCC grade with various breathable waterproof finishings.

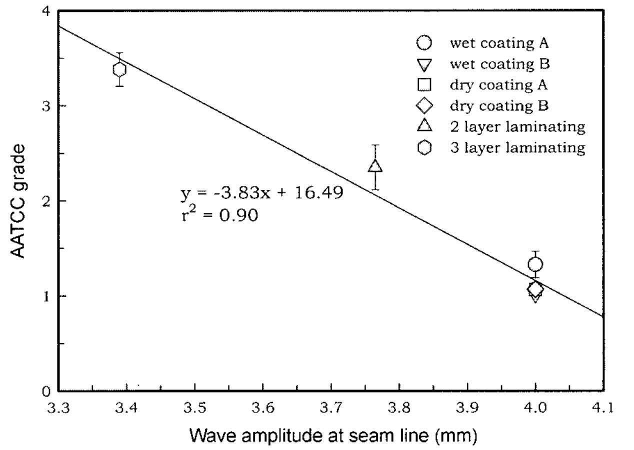


**Figure 5.** The relation between AATCC grade and wave amplitude at seam line.

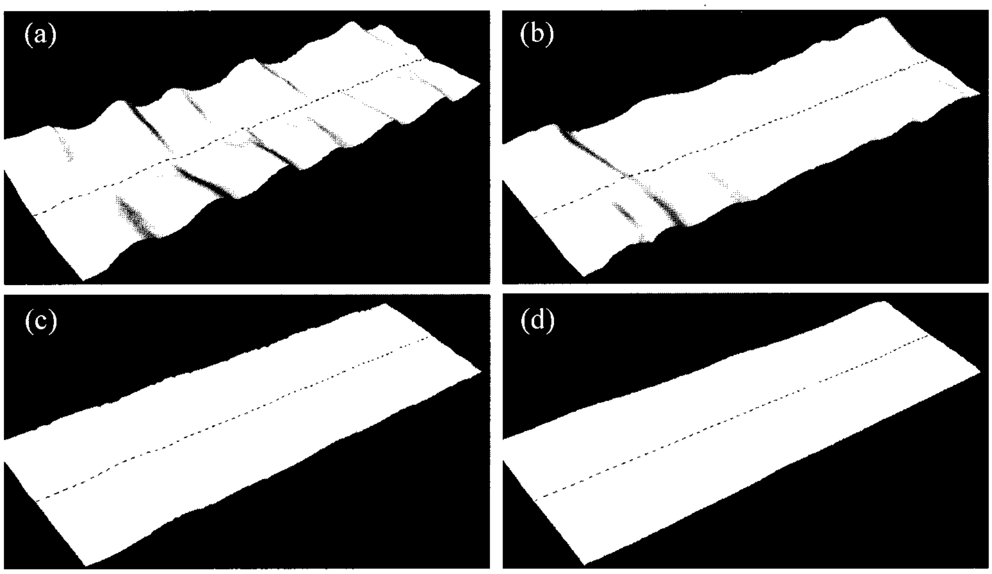


**Figure 4.** Reconstructed three dimensional models of various breathable waterproof fabrics (a) wet coating B type, (b) dry coating B type, (c) 2-layer laminating type, (d) 3-layer laminating type.

between pucker grade and the number of points related wave generation was very low. When we evaluate fabric appearance, compared with ordinary fabrics, wave length and amplitude have more important meaning than the number of wave in

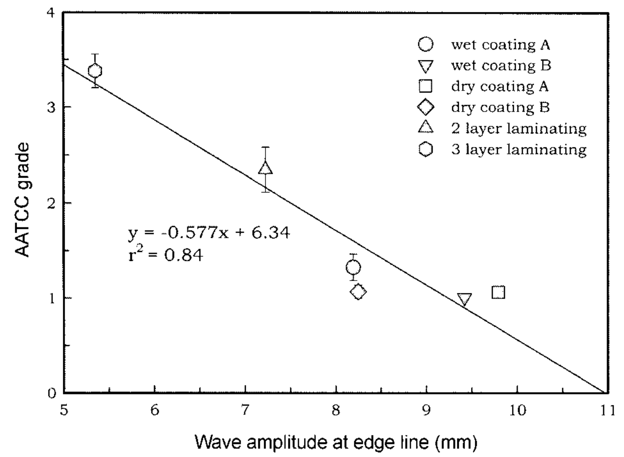


**Figure 6.** The relation between AATCC grade and wave amplitude at edge line.

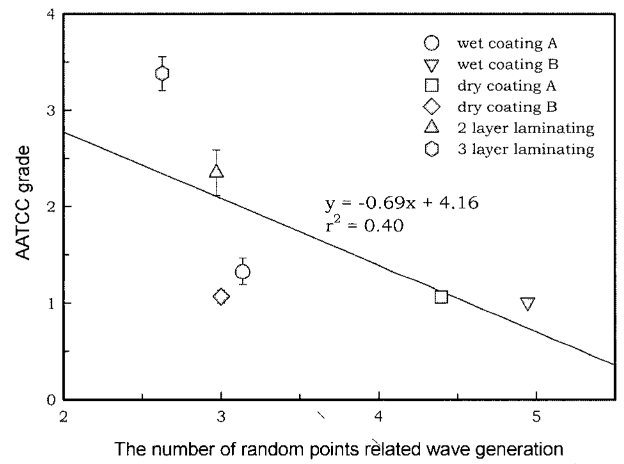


**Figure 7.** The relation between AATCC grade and the number of random points related wave generation.

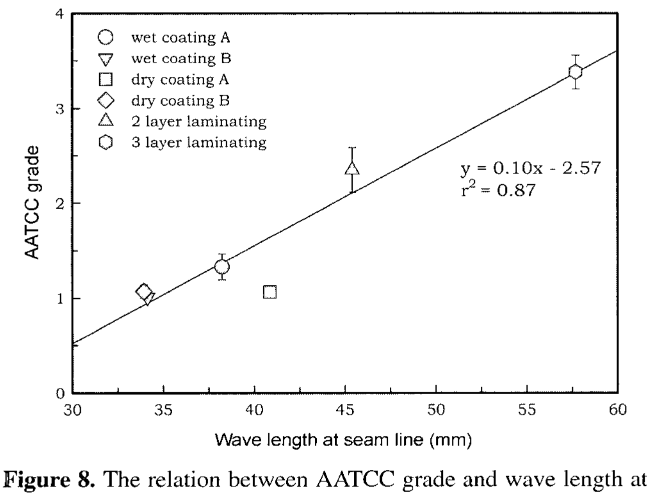


**Figure 8.** The relation between AATCC grade and wave length at seam line.

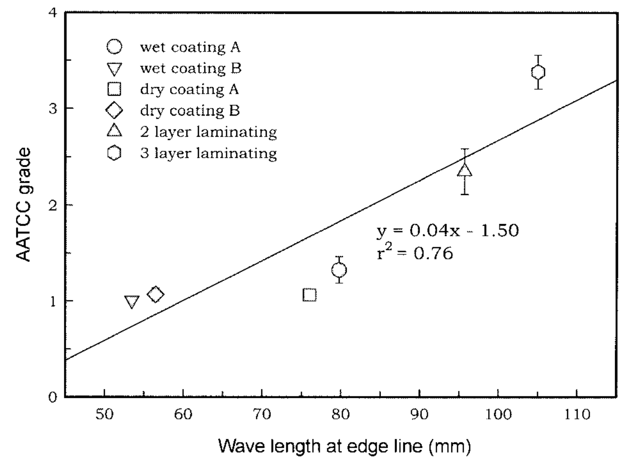


**Figure 9.** The relation between AATCC grade and wave length at edge line.

the breathable waterproof fabrics.

It has been already established that seam pucker in synthetic lightweight fabrics is due to the interaction between the sewing thread and fabric[13,14]. If the fabric is compressible, the threads can recover without causing seam pucker. If the fabric is jammed, the stiffness of the fabric and thread control the occurrence of seam pucker. In this study, one kind of sewing thread was used and there were no significant differences in bending characteristics of thread with finishing methods. Therefore, it was possible to guess that there was another factor affecting the seam pucker.

The seam pucker can be classified to four of tension pucker, inherent pucker, thread/shrinkage pucker, and feeding pucker [15]. The tension pucker occurs when tensed thread in sewing process is extended and makes up buckling on garment. The thread/shrinkage pucker is built up for shrunken thread by washing and after treatment. So it seems that the seam pucker caused by these two factors can be restrained by controlling the thread and there was little influence of thread because same sewing thread was used in this study.

The inherent pucker is caused by the shift of warp and weft due to the insertion of sewing thread. The fabrics used in this study are coated or laminated with polymer membrane on base fabric. So the structural deformation of base fabric by the insertion of sewing thread is prevented, and it seemed that the structural jamming was disturbed, and this caused the local pucker comparing these fabrics with ordinary fabric.

Finally, the feeding pucker, which is also called differential feeding, is caused by feeding error in sewing process. When two pieces of fabric are fed into the gap between a press foot and needle plate, the upper piece gets pressure by press foot and the lower one gets force to the moving direction by the teeth of the needle plate. Therefore, this causes difference of elongation between the two sheets, and seam pucker occurs in the course of recovering these deformation. Generally, sewing a breathable waterproof fabric, the coated side is faced and contacted to the press foot and the teeth of the needle plate. The polymer membrane is so sticky that it affects the different feeding and makes more severe pucker in structural jamming. Judging from these results, to reduce seam pucker of these coating and laminating fabric, it is necessary not only to select a fine needle and thread and enlarge stitch length like the case of common fabric but also to relieve the sticky problem using additives and after treatment. To reduce seam pucker is very important for higher productivity of related goods.

## Conclusions

The changes of the seam characteristics and seam puckering behavior with various breathable waterproof finishing methods were investigated and the conclusions are as follows.

There were differences in 99 % significant level between the seamed fabric and the sealed fabric. Seam breakage was initiated with the breakage of sewing thread, so seam strength after seaming is almost uniform and sewn seam strength and elongation increased with sealing process in all finishing methods. The sealing process played an important role in resistant to external force, and the variations with the finishing methods were not found.

The pucker grade of the laminating type was generally much higher than that of the coating type. The results of the laminating type generally showed lower wave amplitude and longer wave length at seam line and edge line than those of the coating type. We confirmed that wave length and amplitude have more important meaning one by one than the number of wave in the breathable waterproof fabrics. The puckering in breathable waterproof fabrics is mainly occurred by inherent and feeding pucker. The former is due to the insertion of sewing thread and the latter is caused by differential feeding when two pieces of fabric are fed into the gap between a press foot and needle plate.

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