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Journal of the Korean Society of Clothing and Textiles
Vol. 36, No. 6 (2012) p.583~591
http://dx.doi.org/10.5850/JKSCT.2012.36.6.583

Performance Analysis Based on Bonded Surface Designs for Stitchless Welded Products

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Received November 2, 2011; Revised (April 20, 2012; May 22, 2012); Accepted June 11, 2012

Abstract

This study selected three model designs used for air injection type welding clothes designed for insulation purposes and analyzed the performance of each design. The bending characteristics were analyzed in order to identify the flexibility of the welded areas; subsequently, the seam breaking strength and water pressure resistance were analyzed to identify the bonding strength. In addition, two types of waterproof fabric, polyurethane (PU) coated 2 layer and PU laminated 2 layer fabrics, were used for a performance analysis, according to fabric processing specifications. The circle type showed the highest flexibility in the terms of bending characteristics that influence wearability and were followed by the wave and the straight type. In terms of breaking strength, the straight type showed the highest breaking strength, followed by the wave and the circle type. The water pressure resistance analysis found that the wave type was superior to the straight type in terms of water pressure resistance. The wave type is deemed to be a design type suitable for maximizing performance, provided that the issue of stabilization in the welding production process is addressed. Looking at the bending characteristics of waterproof fabric for each specification, the laminating waterproof cloth outperformed the coated waterproof cloth in terms of flexibility. However, in terms of seam breaking strength, the coated waterproof cloth outperformed the laminated cloth. In contrast, the water pressure resistance of the laminated waterproof fabric was found to be higher than the coated waterproof fabric, leading to the conclusion that the bonding strength of the laminated waterproof fabric is higher than that of the coated waterproof fabric based on the assumption of injecting air.

Key words: Breathable fabric, Welding film, Welding technology, Welding process, Seam sealing

I. Introduction

The outdoor fashion market has sharply emerged as a so-called "blue chip" sector of the fashion industry. The domestic market for outdoor fashion was worth 4 trillion won in 2010 (Jo, 2011). This was a six-fold growth in nine years, compared with 520 billion won in 2001, and at 24.5% was approximately nine times the year-to-date market average for the same period of 2.7%. With this growth momentum continuing this year, the outdoor market is expected to be worth a total of 4 trillion won in volume. Some analysts are predicting a rosy future, commenting that "the domestic outdoor fashion market will be worth 5 trillion won sooner or later (Lee, 2011)". In addition to the domestic market, outdoor fashion markets worldwide have been enjoying ultra-high speed growth in a short period of time (Noel, 2008). But the domestic market has outperformed the overseas markets. Germany's 3 trillion won outdoor fashion market has been reported as maintaining an annual grow-

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The authors of this paper would like to thanks the NRF (National Research Foundation), MEST (Ministry of Education, Science and Technology) for sponsoring this research through the Mid-career Researcher Program of NRF/MEST (2008-0364-3-3).

th rate of 3% (Park, 2011). Considering that even in Europe, it is hard to find a single item market growing at an annual rate of around 4%, one gets a sense of the significance of the 10% annual growth rate that the Korean outdoor market has enjoyed in recent years (Park, 2011).

Recently, stitchless welded seam technology has been capturing attention worldwide in the rapidly-growing outdoor fashion industry (Chung, 2008; Wang et al., 2010). Stitchless welded seam technology was developed as the result of an attempt to make zipless connections between Gore Tex fabrics without a sewing process, or to interconnect materials of the same type. However, it has become a key trend in the markets, such as the functional underwear market, in addition to the outdoor fashion market. Following this trend, the domestic outdoor fashion industry has been employing stitchless welded seam technology in diverse ways. But in reality, foreign brands have gained a monopoly on advanced stitchless welded products thanks to their vast financial resources and systemized production facilities covering all production processes, ranging from welding machines to related raw or peripheral materials, as well as end products, in stark contrast with some domestic products, which have been separately produced without any correlations. Moreover, a lack of well-established performance evaluation techniques for welded products has left the domestic outdoor fashion industry with relatively dated stitchless welded seam technologies. In that respect, multilateral and systematic research approaches to stitchless welded seam technology - the core technology in the fast growing outdoor fashion markets - must be given high priority.

Since its introduction, stitchless welded seam technology has been a production method used for outdoor fashion products, and has been spreading across the domestic and international markets. Although the inventor of the stitchless welded seam technology, Gore Tex, holds a vast amount of research and analysis data, the confidential nature of this data has resulted in there being an extremely small amount of research information available for new research. Recently, stitchless welded seam technology has been widely applied to the development of high-value clothes equipped with various functions, as well as being employed for design-oriented reasons. For these reasons, Heat-retaining inner skins can be regarded as stitchless welding clothes of an air-injection type that deserves more attention. As stitchless welded products must offer reliable airtightness performance, rather than simply creating seams, further efforts should be made to determine the reliability of seam performance.

II. Research Methods

1. Materials

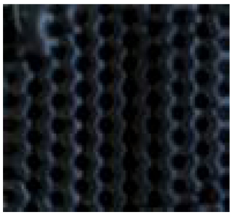
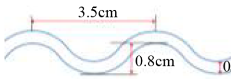
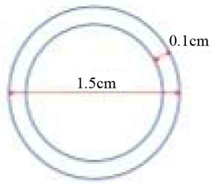
1) Surveys Performed to Select Welding Designs and Fabrics

A series of interviews and data surveys were carried out between 5 February 2009 and 31 August 2011, targeting 23 subjects working in 8 domestic companies specialized in stitchless welded products, in order to screen joining surface designs for air-injection stitchless welded products to be used for analysis, and to select fabrics to be used for testing purposes. Most air-injection stitchless welded products are being used as inner skins of sportswear, and the designs surveyed were the straight, wave, and circle types. No design type other than these three types was found in the market. For this reason, a total of three designs were used as model designs for the joining surfaces of stitchless welded products, and the designs applied to the analysis are depicted in <Table 1>.

2) Welding Conditions

Generally speaking stitchless welded seam technology is applied to clothing products through one of two methods. In the first method, a welding film is inserted between two pieces of fabric in order to seal the fabrics using heat and pressure; in the other method, two materials are melted down and welded by ultra-high frequency waves, and then seam sealing is applied to the top of the welded area in order to maintain the welding strength. Of the two welding methods, the welding method in which welding films are applied to the conventional welding technology of an air injection type was used in the experiment in

Table 1. Air-injection type welded designs

Type	Straight type	Wave type	Circle type
Manufactured goods			
Specimens			
Specific figure			

order to assess the welding performance of the specimens. In the tested welding process, a welding film to which a sheet of transfer paper was attached was affixed to the inner side of one specimen, and then the inner side of the other specimen was put in contact with the welding film after removing the transfer paper prior to performing seam sealing using heat and pressure. The initial welding process, in which a welding film to which a sheet of transfer paper was attached was affixed to one side of a specimen, was performed by applying a pressure of 40 psi for five seconds at 120°C, and the final process, in which two sheets of specimens are interconnected, was performed by applying a pressure of 40 psi for 25 seconds at 120°C. The specifications of the welding machine used in the experiment are detailed in <Table 2>.

2. Testing Methods

1) Analysis of the Specimens Used for Stitchless Welding

The specimens used for the performance analysis of air injection type stitchless welded products were a dry-coated 2 layer PU breathable fabric and a laminated 2 layer PU breathable fabric. In order to compare and analyze the features of the specimens by processing specification, the same kind of nylon Taslan was used as the base fabric of the two specimens. To describe the specifications of the two types of waterproof fabric used as specimens, the water pressure resistance, WVT (Water Vapor Transport), and thickness of the specimens were tested five times. Then, the coated surfaces of the fabrics were analyzed using an SEM (Scanning Electron Microscope). The analysis was performed under controlled conditions - at constant room temperature (20 ± 2°C) with a relative humidity of 65 ± 4%. A water pressure resistance test and a WBT test were conducted in accordance with KS K0591 and KS K 0594, respectively. In addition, compression thickness was measured using the 2 gf/cm^2 pendulum of a FAST-1 compression thickness meter. Notably, the hidden sides of the breathable waterproof fabrics were put into contact with water during the water pressure resistance test. For the SEM

Table 2. Heat press machine specifications

Dimensions	500 × 550 mm	Power	3 kw
Weight	100 kg	Temperature	0 - 300°C
Key feature	Heat transfer occurs in a uniform manner due to the constant temperature of the heat plate		
Pressure	The pressure was fixed at an optimal welding work pressure of 40 psi		

analysis, as welding is applied to the hidden sides of the specimens, the surface characteristics of the hidden sides of the specimens were also examined.

2) *Performance Analysis of Each Air-injection Type Stitchless Welding Design*

(1) Bending Characteristics

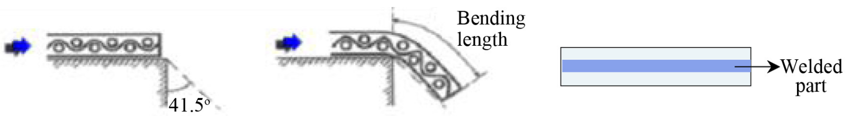
To identify the bending characteristics of seamlessly welded surfaces, ten specimens were created and analyzed by design. The bending characteristics were analyzed using a bending meter produced by FAST System in accordance with the British standard (BS: 3356). Assessments were performed using the built-in photo sensor of the bending meter on the basis of the bending length, which is the travelling distance of a fabric to the point at which the end of the fabric is detected by the photo sensor. The analysis principle and description on the analyzed specimens are clarified in <Fig. 1>.

(2) Seam Breaking Strength

The seam breaking strength of the welded areas was measured at a constant rate of extension - a key feature of stitchless welded areas - in accordance with KS K 0520. The specimens were conditioned by leaving them in a standard testing condition compliant with KS K 0901 for 24 hours. Then, five specimens were created and tested by design. The analysis principles for seam-breaking strength of the stitchless welded surfaces and the details on the specimens are as shown in <Fig. 2>.

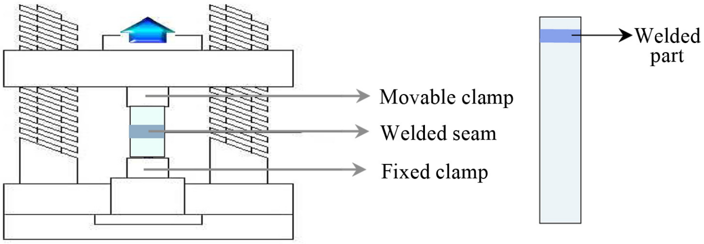
(3) Water Pressure Resistance

Though the desired measurement target was the seam breaking strength of the welded surfaces, it was difficult to identify the amount of strength applied to the welded areas at the time of injecting air. For linear seams, seam breaking strength alone is a sufficient basis for an analysis of welding performance. However, for the wave type and circle type seams, as breaking force is concentrated on the areas in which rupture occurs when analyzing the seam breaking strength of the welded surfaces, it was difficult to identify relevant bonding strength under the assumption of injecting air. To address this issue, the bonding performance was reassessed through a water pressure resistance analysis, rather than by using air pressure. The water pressure resistance was ana-



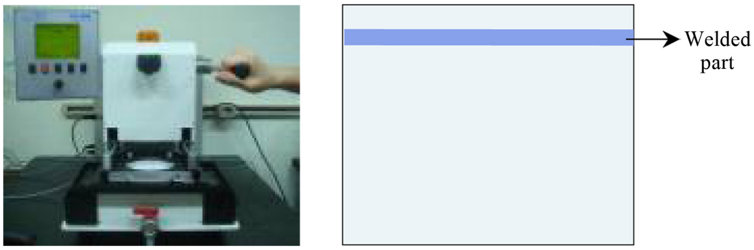
Specimen size: 4 × 15 cm
Specimen welden in the transverse direction of the two pieces of specimens
Bending rididity (m Nm): Fast 2 weight (gf/m^2) × (bendinglength (mm)^3) × 9.807 × 10^{-6}
Bending length (mm): The traveled distance of a specimen to the point at which the end of the fabric reaches the Fast 2 photo sensor

Fig. 1. Bending characteristics analysis method and characteristics of analyzed specimens.



Specimen size: 4 × 15 cm, Specimen welded in the transverse direction of the two specimens
Clamp spacing: 7.6 cm
Clamp travel speed: 30 ± 1 cm/min

Fig. 2. Seam breaking strength analysis method and key features of analyzed specimens.



Specimen size: 20 × 20 cm, Specimen welded at the upper ends of the two specimens
Clamp spacing: 7.6 cm
Clamp travel speed: 30 ± 1 cm/min

Fig. 3. Water pressure resistance analysis method and key features of analyzed specimens.

lyzed by creating five specimens by design type in accordance with KS K 0591:2004, and the water temperature of the tester was $(20 \pm 2)^{o}$C. The water pressure resistance analysis method and the key features of the analyzed specimens are as shown in <Fig. 3>. However, the circle type was excluded from the test because it was impossible to conduct a test due to its inherent water pressure resistance analysis features.

III. Results and Considerations

1. Analysis of the Specimens Used for Stitchless Welding

1) Water Pressure Resistance of the Specimens

For the water pressure resistance of the two types of specimens analyzed in accordance with KS K 0591, it was impossible to measure water pressure resistance levels higher than 20,000 mmH_2O, as 20,000 mmH_2O was specified as the maximum water pressure resistance. A water pressure resistance of 20,000 mmH_2O is an extremely high level to be applied to clothes, and is a pressure level higher than one can experience when wearing clothes in normal conditions. From this, it can be inferred that the specimens used for analysis - the Taslan polyurethane dry coated 2 layer and the Taslan polyurethane laminated 2 layer - are waterproof fabrics that can with stand the maximum water pressure resistance (20,000 mmH_2O) applicable to all kinds of clothes, or water pressure levels higher than that. The results of an analysis of the water pressure resistance of the specimens are detailed in <Table 3>.

2) WVT (Water Vapour Transport) of the Specimens

In terms of the WVT of the two types of specimens, the WVT of the Taslan polyurethane dry coated 2 layer was somewhere around 3,479 $g/m^2 \cdot 24h$, which was relatively low compared with the WVT (3,774 $g/m^2 \cdot 24h$) of the Taslan polyurethane laminated 2 layer. A WVT of around 3,000 $g/m^2 \cdot 24h$ can be regarded as a relatively high WVT level, given that the WVT of waterproof clothes available on the market ranges from 1,000 to 3,000 $g/m^2 \cdot 24h$. The WVT analysis results of the specimens are detailed in <Table 3>.

3) Compression Thickness of the Specimens

The compression thickness of the two specimens was measured using a 2 gf/cm^2pendulum, and it was found that the compression thickness of the Taslan polyurethane dry coated 2 layer and the Taslan polyurethane laminated 2 layer were both approximately 0.19 mm. From this, it was inferred that the two specimens were waterproof fabrics processed in a similar thickness. The results of an analysis of the compression thickness of the specimens are detailed in <Table 3>.

4) SEM (Scanning Electron Microscope)

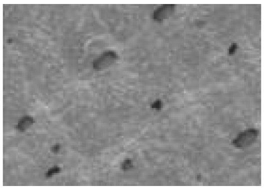
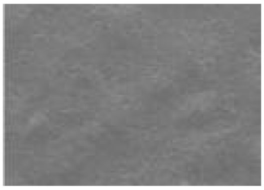
In order to identify the surface shapes of the Taslan polyurethane dry coated 2 layer and the Taslan polyurethane laminated 2 layer fabrics, which are made of the same base fabric but have different waterproof processes applied, the hidden sides of the two specimens were photographed, and the resulting images are shown in <Table 4>. Given the characteristics of the waterproofing processes, the tiny air bubbles that are generally produced over the course of a dry coating process were found on the hidden sides of the Taslan polyurethane dry coated 2 layer, and the sur-

Table 3. Water pressure resistance, water vapor transport, and compression thickness of the specimens

		Water pressure resistance	Water vapor transport	Compression thickness
		mmH_2O	$g/m^2 \cdot 24h$	mm
Fabric 1 Taslan Polyurethane Wet Coated 2-layer	Mean	19,950	3,478.600	0.192
	SD	57.735	11.859	0.00748
Fabric 2 Taslan Polyurethane Laminated 2-layer	Mean	20,000[1)]	3,773.600	0.198
	SD	0.000	28.218	0.004

[1)]The maximum water pressure resistance level that can be achieved by a water pressure resistance analysis in accordance with KS K 0591 is 20,000 mmH_2O; therefore, any water pressure resistance analysis with Fabric 2 should be greater than 20,000 mmH_2O

Table 4. SEM images of the specimens

Fabric 1 Dry coated 2-layer PU breathable fabric	 S4700 5.0 kV 12.5 mm × 100 SE (U)
Fabric 2 Laminated 2-layer PU breathable fabric	 S4700 5.0 kV 12.5 mm × 100 SE (U)

faces of the Taslan polyurethane laminated 2 layer manufactured through laminating processing, in which waterproof films are attached to fabric surfaces, were found to be relatively smooth.

2. Performance Analysis of Each Air Injection Type Stitchless Welding Design

1) Bending Characteristics of the Welded Areas for Each Design

As the bending characteristics of welded areas is a key factor affecting the wearability of clothes, a bending characteristics (rigidity) analysis was performed in this study, based on the cantilever bending length needed for bending fabrics according to unit curvature. As a result, the analysis was performed with the assumption that a rise in the bending length increases the rigidity of welded areas, and a reduction in the bending length makes the welded areas easy-to-bend and more comfortable. The results of an analysis of the bending rigidity of the welded surfaces by design type are detailed in <Table 5>. The results revealed that the overall bending length of the laminated 2 layer was shorter than the coating 2 layer fabric. For this reason, it was determined that the welded laminated fabrics were more prone to bending than the welded coated fabrics when a small amount of force was applied. According to the analysis of the bending length by welding design, the two types of fabrics all exhibited short bending lengths, with the circle type being the shortest, followed by wave type and straight type. However, the circle type and wave type, which had shown good bending performance, exhibited severe fluctuations in bending performance in each area due to the inherent characteristics of the design types. As shown in <Table 5>, the straight type, which is most widely used for welding clothes, showed approximately double the bending length of unwelded areas. In particular, the circle type is more prone to bending than other types even when just a small amount of force is applied, as it has the shortest bending length.

2) Seam Breaking Strength of the Welded Areas by Design

The seam breaking strength of each welding design was analyzed with the max force (N), the highest force required for finally separating welding seams, and the analysis results are detailed in <Table 5>. For the two types of fabric, the max force of the straight type was much higher than that of the other types, and the max force of the wave and circle types was found to be relatively low. It was assumed that the concentration of tensile force on some points of the welded areas might have initiated breaking with a smaller amount of force, compared with the straight

Table 5. Bending rigidity, seam breaking strength, and water pressure resistance of each design

		Bending rigidity		Seam breaking strength[2]		Waterproof	
		cm		max force (N)		mmH_2O	
		Mean	SD	Mean	SD	Mean	SD
Fabric 1 Taslan Polyurethane Wet Coated 2-layer	Unwelded[1]	14.3	0.335	Unmeasurable[3]	Unmeasurable	Unmeasurable[4]	Unmeasurable
	Straight	28.6	0.300	209.76	5.325	12,948	955.04
	Wave	26.4	1.050	88.83	8.938	15,734	2029.25
	Circle	17.4	1.200	48.39	2.804	Unmeasurable	Unmeasurable
Fabric 2 Taslan Polyurethane Laminated 2-layer	Unwelded	12.8	0.332	Unmeasurable	Unmeasurable	Unmeasurable	Unmeasurable
	Straight	24.4	0.374	172.89	3.590	15,352	817.69
	Wave	22.8	1.188	58.11	3.091	17,720	1608.80
	Circle	15.8	1.364	32.56	3.073	Unmeasurable	Unmeasurable

[1]"Unwelded" indicates cases in which two sheets of specimens were overlapped for testing purposes.
[2]Seam-breaking strength: The highest force needed for bursting welded seams: Max force (N).
[3]The seam-breaking strength of the unwelded specimens was unmeasurable.
[4]The waterproof of the non-welded specimens and the circular-type specimens with welded surfaces unblocked was immeasurable.

type. Therefore, the welded surfaces of the coating 2 layer fabric showed relatively higher bonding strength than those of the laminated 2 layer. In terms of the bonding strength of each design, the bonding strength of the straight type was the highest, followed by the wave type and the circle type.

3) Water Pressure Resistance of Welded Surfaces by Design

The seam breaking strength of ordinary straight-type welded surfaces can be analyzed based on the "max force (N)" - which is the highest force needed for the final separation of welded areas. However, it was difficult to analyze the joining features of air-injection welded products using conventional methods. For this reason, the water pressure resistance analysis method, which can closely simulate air injection circumstances, was employed. When the bonding strength of welded surfaces was measured by water pressure resistance, the results differed from those found through simple seam breaking strength analysis. This runs counter to the seam breaking analysis results, as described above. Another key feature revealed by the analysis is that the water pressure resistance of the laminated 2 layer fabrics is generally higher than that of the coating 2 layer fabrics. This coincides with the seam breaking analysis results, as described above.

IV. Conclusions and Suggestions

The purpose of this study was to identify the main design types used for conventional air injection welding products among the stitchless welding clothes. PU coating 2 layer waterproof fabric and PU laminating 2 layer waterproof fabric were manufactured and tested for the purpose of performance analysis. The two types of waterproof fabric used as specimens both proved to be high performance waterproof fabrics compared with the waterproof fabrics that have commonly been used for clothes available on the market. In addition, even though the laminated waterproof fabric was slightly superior to the coated cloth in terms of compression thickness, in the area of performance, the two types of waterproof fabric showed no significant differences.

A performance comparison between the welded areas of the laminating 2 layer and the coating 2 layer revealed that the short bending length made the laminating 2 layer fabric more prone to bending over the coating 2 layer fabric, even when a small amount of force is applied, while achieving better performance in the water pressure resistance test in a condition similar to actual air injecting circumstances.

A performance comparison among the welded areas of the circle type, wave type, and straight type also revealed a gradual decrease in bending length, in the following order: circle type, wave type, and straight type. However, the circle type was inevitably excluded from the water pressure resistance test in a condition similar to air injection circumstances. As a result, the comparison between the wave type and the straight type, after circle type was excluded, revealed that the wave type outperformed the straight type in terms of water pressure resistance.

In general, the bonding features of welded surfaces have been analyzed by evaluating breaking strength. Such a performance analysis method might be applied to surfaces that are welded rather than joined through conventional sewing work without raising further concerns. However, for air injection welding surfaces, the force applied to welded surfaces by air injection must be identified. To put it another way, if general seam breaking strength is used for performance analysis, the entire force is concentrated on the seam starting point on a target welded surface. As a result, it is difficult to consider the force as the force applied to the welded surfaces at the time of air injection. Surveys of companies holding welding technologies indicate that such companies have been eager to find a solution to this issue. However, for the circle type, it was impossible to perform a water pressure resistance analysis capable of assessing water pressure by storing water. Ultimately, it seems that another testing method that can assess the circle type should be promoted through subsequent studies.

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