EFFECT OF INTERLINING FUSING PARAMETERS ON PEEL STRENGTH AND SHRINKAGE OF FUSED FABRIC

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ABSTRACT

The peel strength and shrinkage of fused fabrics play an important role in the quality of garment products. Fusing parameters significantly affect these characteristics. This study aims to determine the influence of fusing temperature, pressure, and time on the peel strength and shrinkage of fused fabrics. Warp Knitted Interlining was fused onto 100% PES fabric, commonly used for women's suits, using the Hashima HP-1000LW press machine. The peel strength of the fused fabric samples was measured on the Tensile Tinius Olsen device. The shrinkage of the samples was determined according to ISO 3579:2011. The relationship between fusing parameters and the peel strength and shrinkage of fused fabrics was analyzed using the Bayesian Model Average in R software. The results indicate a significant multivariate linear relationship between the fusing conditions and peel strength ($R^2 = 0.945$) and fabric shrinkage ($R^2 = 0.528$). As the fusing temperature, time, and pressure increase, the warp peel strength improves; as the fusing temperature increases and the fusing pressure decreases, fabric shrinkage after fusing increases. The effect of fusing time on shrinkage is minimal within the scope of this study.

Keywords: *Interlining, peel strength, fusing parameters, fabric shrinkage.*

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1. INTRODUCTION

In the garment industry, the quality of fabric interlining fusing plays a crucial role in the overall product quality. The fusing process not only enhances the stiffness and maintains the shape of the product but also ensures aesthetic and functional requirements [1]. The quality of the fused bond, including peel strength and fabric shrinkage, is influenced by various factors [2].

Peel strength, representing the ability to resist mechanical forces before the bond between fabric and interlining is broken, is a critical factor for product durability during use [3]. Several studies have shown that fabric, interlining, and technological parameters such as fusing temperature, pressure, and time all affect the bonding strength between the interlining and fabric after fusing [4-6]. Fabrics with a loose structure or low mechanical strength become more durable and achieve better shape retention after interlining fusing [7-9]. Girija R. and Rajagopal S. predicted the bonding strength of fused shirting fabrics before and after washing based on fabric composition, interlining weight, and fusing temperature [10]. The results revealed that heavier interlining (250g/m²) requires higher fusing temperatures compared to lighter interlining (225g/m²). After washing, the bonding strength of samples fused at higher temperatures decreased. Maintaining a high fusing temperature without considering interlining weight can reduce bonding strength after washing [10]. Soon Young Yun et al. optimized fusing conditions to maximize bonding strength between 11 fabrics and interlinings before and after drying using the Taguchi method. Four parameters, including interlining type, fusing temperature, pressure, and time, were selected for optimization [11]. Sashka Golomeova-Longurova et al. studied the selection of interlinings for men's shirts [12]. Abu Bakar Siddiquee et al. investigated the effect of interlining orientation on the physical and mechanical properties of men's waistband fabrics. The results identified the most suitable cutting orientations (lengthwise, crosswise, 30º bias, 45º bias, and 60º bias) for interlinings in three fabric types: 2/1 stretch twill, dobby stretch denim, and non-stretch denim [13].

In addition, the shrinkage of fused fabrics is a critical indicator that affects the dimensional stability and shape of the product. Factors such as temperature, pressure, and humidity in the fusing environment can influence fabric shrinkage, leading to deformation or reduced product quality [5]. Incompatibility between interlining and fabric or unsuitable fusing conditions may result in undesirable shrinkage of the fused fabric [8, 9]. Kaushal Raj Sharma et al. studied the impact of interlining on the drape characteristics of fabrics used for men's suits [14]. Kavati Phebe et al. evaluated the performance characteristics of three types of interlinings fused with napa sheep leather, focusing on bending properties, softness, bonding strength, shrinkage, tensile strength, and tear strength. Interlinings woven from nylon/cotton fibers demonstrated the best performance among the studied types [15]. G.A. Robinson et al. investigated the shrinkage of 2/2 twill wool/polyester fabrics fused with cotton/rayon interlining using polyamide resin. The results indicated that the fabric shrinkage was negligible after fusing [16].

Although there have been several studies on the factors influencing the bonding quality of fused fabrics, detailed understanding regarding the impact of technological parameters on peel strength and shrinkage of fabrics remains limited. This study aims to clarify the impact of fusing temperature, pressure, and time of Warp Knitted Interlining on the peel strength and shrinkage of 100% PES fabric after fusing, contributing to building the foundation for quality improvement and production efficiency of garment products.

2. MATERIALS AND METHODS

The woven fabric made of 100% PES, commonly used for women's blazers, was selected for the experiment. This type of product is often fused with interlining over a large area. The interlining chosen for the experiment is Warp Knitted Interlining, suitable for women's blazers (Table 1).

Table 1. Technical specifications of fabric and fusible interlining used in the experiment

Fabric		Interlining	
Composition	100% PES	Type	Warp Knitted Interlining
Weave	Twill 2/1	Composition	100% polyester
Weft density	350 (yarns/10cm)	Construction	Tricot
Warp density	420 (yarns/10cm)	Adhesive bonding	PES + PA
Weft yarn count	Ne 20	Weight	80g/m^2
Warp yarn count	Ne 32	Thick	0,18mm
Weight	270g/m^2		

To determine the influence of fusing technological parameters, including fusing pressure, temperature, and time, on the peel strength of fused fabric samples, 125 experiments were established with the following parameters:

- Fusing pressure (variable name: *press*) was selected at five levels: 1.8kg/cm^2, 2.2kg/cm^2, 2.6kg/cm^2, 3.0kg/cm^2, and 3.4kg/cm^2.
- Fusing temperature (variable name: *temp*) was selected at five levels: 140°C, 145°C, 150°C, 155°C, and 160°C.
- Fusing time (variable name: *time*) was selected at five levels: 12 seconds, 15 seconds, 18 seconds, 21 seconds, and 24 seconds.

The temperature, pressure, and fusing time were selected based on the suggestions from the interlining manufacturer, the type of interlining, the type of fabric, and the practical experience. Each experiment was applied to three samples. The levels of these three parameters were chosen to ensure the appearance requirements of the fused fabric samples were met.

The experimental samples were prepared according to ISO 3579:2011 standards, with dimensions of 500mm x 500mm [17]. A total of 375 fabric and interlining samples were prepared for the 125 experiments. A region with dimensions of 350mm x 350mm was marked in the center of each sample. Fusing was performed on the samples using a Hashima HP-1000LW press machine under environmental conditions of 30°C and relative humidity of 80% according to the 125 established experiments.

Measurement process: The fabric's dimension in the warp direction after fusing (L_1, mm) was measured based on the initially marked position, and the results were recorded. The fabric's warp shrinkage after fusing was determined in accordance with the ISO 3579:2011 standard:

$$\text{Shrinkage} = \frac{L_0 - L_1}{L_0}.100\% \qquad (1)$$

Where, L_0 represents the initial warp dimension of the sample (350mm). L_1 represents the warp dimension of the sample measured after fusing.

In this study, the weft shrinkage of fused fabric was not determined for the 125 samples because preliminary tests on 20 fused fabric samples showed that the weft shrinkage after fusing was negligible. As a result, weft shrinkage was excluded from this study.

After determining the warp shrinkage of the samples, the fused fabric was cut into pieces measuring 380mm x 380mm to study the peel strength. The samples were washed, and dried according to the ASTM D2724-07:2015b standard [18]. Subsequently, each sample was further cut into three smaller specimens measuring 152mm x 51mm to test the peel strength (Figs. 1 and 2).

The specimens were cut along the warp direction because most fused interlining areas on fabrics are aligned with the warp direction. On each small specimen, a section of 76mm in length was marked along the specimen's length (Fig. 2). The interlining and fabric layers were gently separated along the marked length before being tested for peel strength.

The peel strength (ST) between the interlining and fabric was measured using the Tinius Olsen Tensile Tester, following the ASTM D2724-07:2015b standard under standard conditions.

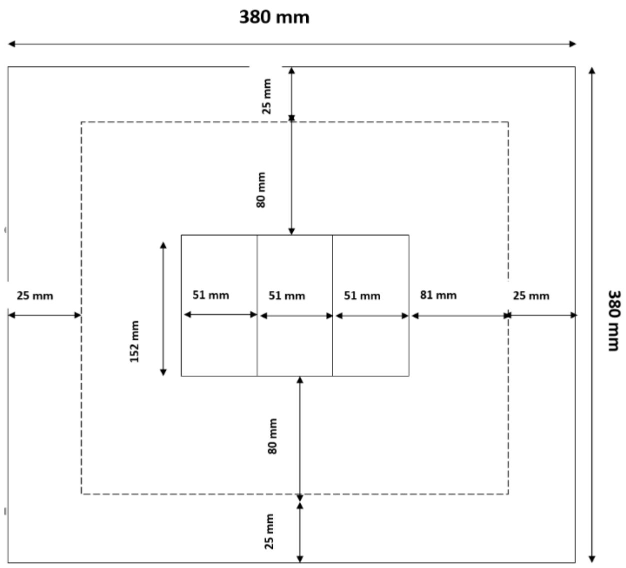

Fig. 1. Schematic diagram of cutting samples for peel strength testing from fused fabric samples

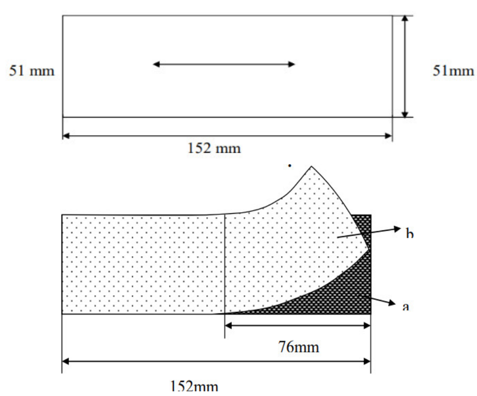

Fig. 2. Sample for peel strength testing

The distance between the lower and upper clamps of the Tensile Tinius Olsen device is set to 25mm. The testing machine operates at a speed of 5 ± 2mm/s. The clamps must securely hold the test specimen to prevent slipping or tearing during the measurement.

The Bayesian Model Averaging (BMA) was used to determine the optimal model that represents the relationship between the peel strength of fused samples or shrinkage and the fusing temperature, time, and pressure using R software. The Bayesian Information Criterion (BIC) and the coefficient of determination R^2 were used to evaluate and select the optimal model [19, 20]. The BIC measures the balance between model complexity (number of variables) and model fitness based on the Residual Sum of Squares (RSS):

$$BIC = n\log(RSS_p) + p\log n \quad (2)$$

Where, n is the sample size, and p is the number of input variables in the model.

A lower BIC value indicates a better model. The model with fewer variables that explains the most data is considered the optimal model.

3. RESULTS AND DISCUSSION

3.1. Effect of Fusing Parameters on Peel Strength

The peel strength of 125 fused fabric samples ranged from 107.65mN/mm to 231.28mN/mm, with an average value of 168.76mN/mm and a standard deviation of 19.64mN/mm. The 95% confidence interval (CI) for peel strength (ST) is (130.26; 207.26) mN/mm. The values of peel strength closely follow a normal distribution. The experimental data processed in R software using BMA resulted in an optimal model as follows:

$$ST = -183.492 + 1.891*temp + 3.123*time + 4.767*press \quad (3)$$

$R^2 = 0.945$ and BIC = -347.795, the model's probability is 1.

The residuals of the model range from -19.65 to 21.05, with an average value of -0.37, indicating that the model's error is negligible.

The optimal model represents the relationship between peel strength and the conditioning parameters with a Multiple R-squared (R^2) = 0.945. This means that the variation in temperature, pressure, and bonding time explains 94.5% of the variation in the bond strength of the samples. The bonding temperature, time, and pressure are positively correlated with bond strength. The Adjusted R-squared = 0.944 shows that the model is not overly influenced by the number of independent variables. The *p-value* < 2.2e-16 indicates that the model is statistically significant. This confirms that the three variables (fusing temperature, pressure, and time) all have a significant effect on peel strength. The regression coefficient for temperature (*temp*) is 1.891, indicating that for every 1°C increase in fusing temperature, the peel strength increases by 1.891mN/mm, assuming that time and pressure remain constant. The *p-value* = 1.50e-10 shows that the effect of fusing temperature is statistically significant. The regression coefficient for fusing time (*time*) is 3.123, indicating that for every 1-second increase in fusing time, the peel strength increases by 3.123mN/mm, assuming that temperature and pressure remain constant. The *p-value* = 9.06e-10 shows that fusing time also significantly affects peel strength. The regression coefficient for pressure (*press*) is 4.767, indicating that for every 1kg increase in fusing pressure, the peel strength increases by 4.767mN/mm, assuming that temperature and time remain constant.

The peel strength (ST) of the sample increases as the temperature, time, and pressure increase within the studied range. However, it is important not to exceed the material's tolerance, as excessive temperature, fusing time, or pressure can lead to fabric deformation or damage during the fusing process. The fused fabric with the highest temperature, time, and pressure (corresponding to 160°C, 24 seconds, 3.4kg) had the highest peel strength (231.28mN/mm) within the study range.

3.2. Effect of fusing Parameters on fused Fabric Shrinkage

The shrinkage of 125 fused fabric samples ranged from 0.67% to 1.97%, with an average value of 1.56% and a standard deviation of 0.157%. The 95% confidence interval (*CI*) for shrinkage is (1.25%; 1.87%).

The experimental data were analyzed using the R software with the BMA technique, resulting in two models (Fig. 3):

Model 1: Shrinkage = -0,1032 + 0,0131*temp - 0,1164*press (4)

R^2 = 0.528 and BIC = -84.09, Probability of model is 0.816

Model 2:

Shrinkage = -0,1584 + 0,0131*temp + 0,0031*time - 0,1164*press (5)

R^2 = 0.535 and BIC = -81.11; Probability of model is 0.184

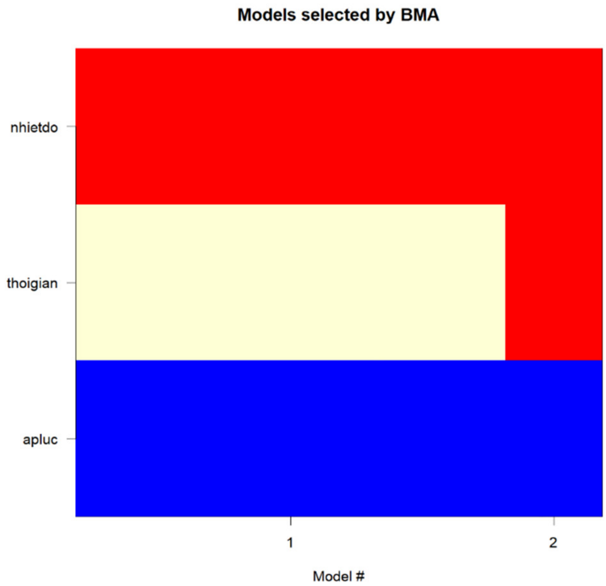

Fig. 3. BMA Plot of Optimal Models

Model 1 was selected as the optimal model since the statistical indicators of the two models differ only slightly, and the probability of Model 1 (0.816) is significantly higher than that of Model 2 (0.184). For Model 1, the residual values range from -0.756 to 0.459, with a median value approximately equal to 0.006. This indicates that the model's error is negligible.

The optimal model demonstrates the relationship between shrinkage and conditioning parameters with a Multiple R-squared (R^2) = 0.528. This indicates that the variation in fusing temperature and pressure explains 52.8% of the variation in the shrinkage of the sample. The fusing temperature is positively correlated with shrinkage, while the fusing pressure is inversely correlated with shrinkage. The Adjusted R-squared = 0.522, which is close to R^2, suggesting that the model is not significantly influenced by the number of independent variables. The *p-value* < 2.2e-16 indicates that the model is statistically significant. Both temperature (*temp*) and pressure (*press*) have a significant impact on shrinkage. The regression coefficient of the variable "*temp*" is 0.0131, indicating that when the fusing temperature increases by 1°C, the peel strength increases by 0.0131mN/mm, assuming the fusing pressure remains constant. The *p-value* < 2e-16 demonstrates that the effect of the fusing temperature is statistically significant. The regression coefficient for pressure (*press*) is -0.1164, which shows that for every 1 kg increase in fusing pressure, the shrinkage decreases by 0.1164%, assuming that fusing temperature remains constant. The *p-value* = 4.4e-10 demonstrates that pressure also significantly affects shrinkage.

Thus, both temperature and pressure have a significant impact on the shrinkage of the fused fabric. Decreasing fusing temperature and increasing pressure reduce the shrinkage of the sample. The fused fabric with the lowest temperature (140°C) and the highest pressure (3.4kg) had the lowest shrinkage (231.28mN/mm) within the study range. However, it is important to not reduce the temperature too much, as insufficient heat will prevent the adhesive from fully melting, compromising the peel strength. On the other hand, excessively high pressure will cause fabric deformation after fusing

4. CONCLUSION

The relationship between the peel strength and shrinkage of the fabric in the warp direction, as well as the fusing temperature, time, and pressure, has been established. The fusing temperature, time, and pressure significantly affect the peel strength in the warp direction of the fused fabric sample. As fusing temperature, time, and pressure increase, the peel strength (ST) in the warp direction also increases within the study range according to the model:

ST = -183,492 + 1,891*temp + 3,123*time + 4,767*press (R^2 = 0.9449).

Both fusing temperature and pressure significantly affect the warp shrinkage of the fused fabric. When the fusing temperature increases and the pressure decreases, the shrinkage of the fused fabric increases according to the model:

Shrinkage = -0,1032 + 0,0131*temp - 0,1164*press (R^2 = 0.5276)

However, the fusing time tested in the study did not have a significant impact on the shrinkage of the fused fabric.

For the chosen fabric and interlining, to achieve high peel strength of the fused fabric, the fusing temperature, time, and pressure should be selected at high levels that the fabric and interlining can tolerate without damaging them. To minimize shrinkage, the fusing temperature should be kept as low as possible while ensuring that the adhesive melts properly and productivity is maintained. The fusing pressure should also be kept high, but not to the point where surface quality and fabric structure are compromised. However, it is crucial to balance between achieving high peel strength and minimizing shrinkage in the sample.

5. RESEARCH LIMITATION

The extent to which the variation in shrinkage of the fused fabric sample is explained by the variation in fusing temperature, pressure, and time is limited. This suggests that a nonlinear model may be required to more accurately describe the relationship between shrinkage and these fusing parameters. A nonlinear approach could potentially capture more complex interactions between the factors and provide a more precise understanding of their effects on fused fabric shrinkage. Exploring such a model could help improve the predictive capability of the fusing process and optimize the quality of the final product.

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