Effects of dot-type adhesive and yarn float on shear stiffness of laminated fabric with interlining

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Abstract
Shear model for laminated fabrics that takes into account the adhesive effect was proposed. The effect of fixing two or more interlacing points by adhesive on the shear stiffness of laminated fabric was taken into account. Using the proposed mode and the regression equation for the increase ratio (*IR*), a prediction method for shear stiffness of laminated fabrics was proposed and verified experimentally. *IR* of the shear stiffness of face fabric due to bonding interlining was calculated by dividing differences between the shear stiffness of laminated fabrics and pressed adhesive interlining by the initial shear stiffness of face fabric. The relationships among the ratio of fixed interlacing points, *IR* and adhesive mass were investigated. It is clear that *IR* is affected by the adhesive fixing of adjacent floating yarns in addition to the fixing of interlacing points. *IR* was experimentally obtained, and a regression equation was formulated as a function of the mass of the adhesive agent. The shear stiffness values of laminated fabrics were able to be predicted more precisely by dividing the regression area according to the mass of adhesive applied during interlining.

Introduction

Large shear deformations generated by relatively low stress are a mechanical property of fabrics that differentiates fabrics from other sheet materials such as a paper. The shear deformation of fabrics has been investigated in experiments and using structural models of fabrics. Skelton [1] investigated the limit of shear deformation according to geometrical parameters and proposed an equation for approximating the shear stiffness from a fabric's weight and thickness. Kawabata et al. [2] proposed general in-plane finite deformation theory including the shear deformation taking into account the interlacing yarn torque. The model was verified experimentally by Niwa et al. [3]. Wang et al. [5] investigated the mechanical interactions of warp and weft yarns during the shear deformation. Zheng et al. [4] introduced a new shear test for woven fabrics based on the trellis shear model, obtained from shear deformation experiments under the low tensile stress.

In clothing production, it is necessary to control the shear stiffness of fabrics to form and to keep an intended shape. This control is often accomplished by bonding an adhesive interlining. It is also known that the incorporation of adhesive interlining affects the bending rigidity and shear stiffness of laminated fabric [6, 7, 12–14]. Kim et al. [8–11] proposed the laminate theory of bending and experimental methods to predict the bending rigidity of laminated fabrics.

In this paper, we use the shear force per unit width instead of stress for the shear stiffness. In the laminate theory, the shear stiffness of a laminated fabric (G_l) is given by

$$G_l = G_f + G_i, \qquad (1)$$

where G_f and G_i are the values of the shear stiffness of the face fabric and interlining, respectively. However, the experimental shear stiffness of a laminated fabric typically has a different relationship because of the effects of the adhesive agent, whereby

$$G_l > G_f + G_i . \qquad (2)$$

Shishoo et al. [12] considered shear properties as important factors of the effects of adhesive interlining in the clothing manufacture and measured the shear stiffness values of various laminated fabrics. Fan et al. [13] investigated the relationship between the mechanical properties of laminated fabrics and the use of adhesive interlining, both experimentally and statistically, and developed regression equations. However, they did not determine quantitative effects of the adhesive agent on the shear stiffness of laminated fabrics.

Kim and Takatera [14] investigated a method for controlling the shear stiffness of plain fabric bonding employing dot-type adhesive interlining. Their results demonstrated that the change in the shear stiffness of the fabric depended on the number of interlacement points fixed by adhesive dots, such that a greater number of fixed positions increased the shear stiffness. They assumed the interlacement points fixed by adhesive dots increase the shear stiffness of the face fabric and proposed the model

$$G_l = G_i + \left(IR \times G_f\right). \qquad (3)$$

wherer IR is increasing ratio from the relationship among shear stiffness values for the laminated fabric and its components.

They used the shear stiffness of the pressed interlining before bonding for G_i to account for the effect of adhesive agent after bonding. They experimentally obtained the IR, and predicted the shear stiffness of laminated fabric of plain face fabric.

Kim and Takatera [14] were thus able to predict the shear stiffness of laminated fabrics in preliminary experiments on fabrics having various adhesive interlinings. However, in their work, they observed that the experimental shear stiffness values of laminated fabrics with the relatively high adhesive mass were greater than predicted shear stiffness values. Moreover, they did not investigate the detailed mechanism of applicability for another weave.

We attribute those prediction errors to the fixing of two or more interlacing points by single adhesive dots having sufficiently large mass. At the same time, the adhesive dots are expected to fix adjacent pairs of parallel yarns. It is necessary to confirm these ideas experimentally. In this study, we investigated two phenomena for plain, twill and satin fabrics. From the results, we propose a method of predicting the shear stiffness values of laminated fabrics from limited experimental data. We investigated the shear stiffness of laminated woven fabric with an interlining of adhesive dot-type as shown in Figure 1.

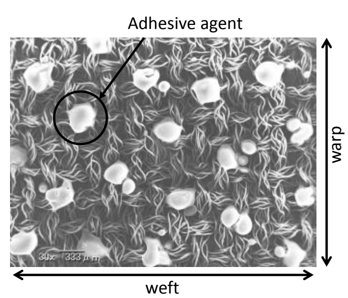


Figure 1. Surface of an adhesive interlining

Theoretical

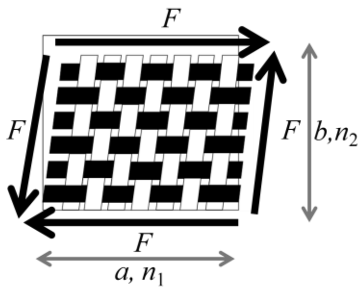


Figure 2. Shear model for a section of plain fabric

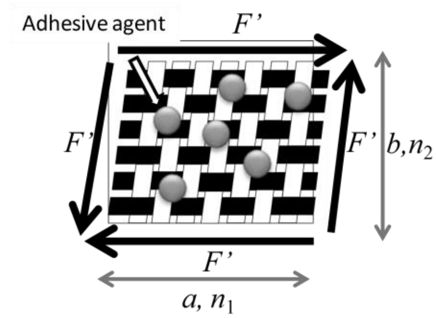


Figure 3. Shear model for a section of plain fabric bonding with the adhesive agent

We propose a shear model for plain fabric, twill fabric, and plain–twill laminated fabric. Figure 2 shows a shear model for a section of plain fabric, while Figure 3 shows the shear model for a section of plain fabric bonding with adhesive agent.

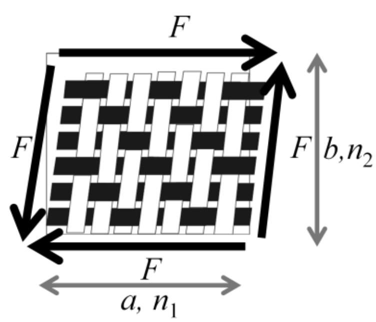


Figure 4. Shear model for a section of twill fabric

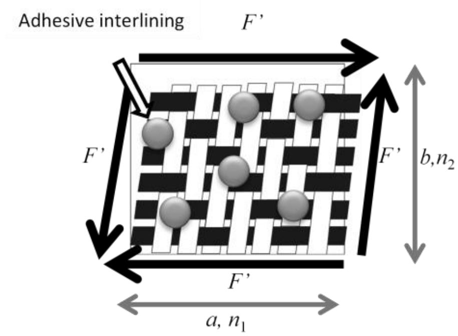


Figure 5. Shear model for a section of twill fabric bonding with adhesive agent

Figure 4 shows a shear model of a section of twill fabric while Figure 5 shows the shear model of a section of twill fabric bonding with the adhesive agent. The structures of interlacing points are different for twill fabric and plain fabric, with the former having floating yarns as shown in Figure 4. The floating yarns may be fixed by the adhesive agent and may affect the shear stiffness of laminated fabric. The concept of floating yarns will be applied to other weaves such as the satin weave.

In the shear model of plain fabric, the external shear force couple T is

$$T = F \times a \times b = F \times b \times a\,, \qquad (4)$$

where F is the conjugate force acting in the unit width,
a and b are the width and length of the fabric section and then Fa and Fb are shear forces acting on the side a and b, respectively.

This couple is balanced by the yarn interlacing torque according to

$$T = F \times a \times b = (an_1 \times bn_2)t \quad \text{or} \quad F = (n_1 \times n_2)t\,, \ (5)$$

where t is the torque acting at the interlacing points of the face fabric and n_1 and n_2 are the quantities of yarn per the unit width along the two sides of the fabric section.

When we put total quantity of interlacing points N in unit area as

$$N = n_1 \times n_2\,, \qquad (6)$$

we can obtain following equation

$$F = N \times t\,. \qquad (7)$$

A model representing plain fabric with adhesive agent is shown in Figure 3. The shear force F' at the face of a fabric section incorporating an adhesive agent after bonding, can be expressed as

$$F' = CNt' + (1 - C)Nt\,, \qquad (8)$$

where t' is the torque at the interlacing points fixed by the adhesive, C is the ratio of yarn interlacing points fixed by the adhesive to all interlacing points. The increase rate of the shear stiffness IR can be expressed by a relationship between C and yarn torque:

$$IR = F'/F = C(t'/t - 1) + 1. \quad (9)$$

C is affected by the adhesive agent, which soaks into the interlacing points of the yarn [14]. In addition, the mass of each adhesive dot and the concentration of dots affect C. If we assume that the area of a dot is proportional to the mass of a dot, C can be expressed as a linear function of g either the adhesive dot area or mass as in

$$C = g(A_d \times N_d), \quad (10)$$

where A_d is the area of one dot, N_d is the number of adhesive dots per the unit area of fabric. C can then be expressed as a function f of the adhesive mass per unit area M as

$$C = f(M), \qquad (11)$$

$$M = M_d \times N_d\,, \quad (12)$$

where M_d is the mass per dot.

In equation (10), C is proportional to M, meaning that the shear stiffness of the face fabric is also proportional to M. To confirm this model, however, an experimental verification of equation (12) is necessary.

In the case of twill or satin fabric with a long float, the shear model will be different from that of plain fabric because of the floating yarns. An adhesive dot may fix a pair of adjacent parallel yarns in the case of a weave with a long float such as twill and satin fabric. Thus, for the model of twill fabric, equation (8) is rewritten as

$$F' = (C_a + C_j)N\,t' + (1 - C_a - C_j)N\,t. \qquad (13)$$

Where: C_a is the ratio of interlacing points fixed by the adhesive agent and C_j is the ratio of floating yarns points fixed by the adhesive agent. We assume that the effects of C_a and C_j are the same.
IR can then be expressed with C_a and C_j as

$$IR = F'/F = C_a(t'/t - 1) + C_j(t''/t - 1) + 1. \qquad (14)$$

Where: C_a and C_j can then be expressed as a linear function with respect to the adhesive mass per unit area (M_a and M_j) as

$$C_a = f(M_a), \qquad (15)$$

$$C_j = f(M_j). \qquad (16)$$

Returning to the equation (1), if we incorporate the effects of the adhesive on the fabric face and the interlining as C_f and C_i, respectively, then the shear stiffness of the laminated fabric is given by

$$G_l = C_f G_f + C_i G_i\,, \qquad (17)$$

Where

$$G_f = C_a + C_j\,. \qquad (18)$$

The shear stiffness of the interlining with adhesive may be considered equal to that of pressed interlining, G_{pi}, such that

$$G_{pi} = C_i G_i\,. \qquad (19)$$

This leads to

$$G_l = C_f G_f + G_{pi}\,. \qquad (20)$$

IR can be obtained by inserting experimentally obtained values of the shear stiffness for the laminated fabric and its components into equation (10):

$$IR = C_f = \left(G_l - G_{pi}\right)/G_{pf}, \qquad (21)$$

where: G_{pi} is the shear stiffness of the pressed adhesive interlining and G_{pf} is the shear stiffness of the pressed face fabric, because the shear stiffness of the fabric face is modified by pressing during the bonding process even without the adhesive effect. It has, in fact, been shown that the shear stiffness values of face fabric and adhesive interlining are both increased by the pressing procedure used during the bonding process. Therefore, in this study, the face fabric and adhesive interlining samples were pressed separately from one another [10]. The value of *C* for each sample was calculated under the assumption that the adhesive dots on the fabric face were positioned as shown in Figure 6. According to the proposed model, *IR* is proportional to *C* and *C* is proportional to *M*. Therefore, if the model is valid, the shear stiffness of a laminated fabric may be calculated using the values of *IR* as a function of *M*. According to equation (21), the shear stiffness of the laminated fabric, G_{lcal}, can be predicted as

$$G_{lcal} = G_{pi} + \left(IR \times G_{pf}\right). \qquad (22)$$

This is a simple model that assumes that an adhesive dot is affixed at each interlacing point. When the mass of adhesive dot becomes large, however, it may fix two or more interlacing points. Moreover, in the case of weave with a long float, an adhesive dot may fix a pair of adjacent parallel yarns. In such cases, *IR* may depend on the adhesive area, the number of interlacing points and the float length.

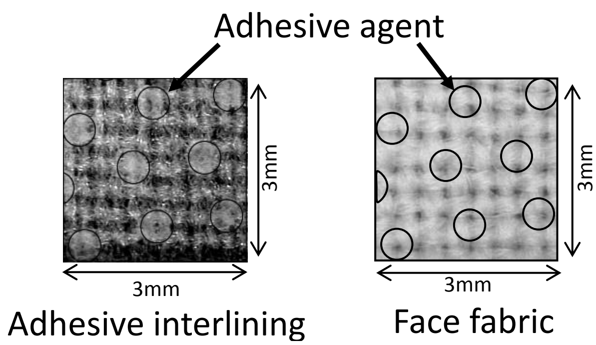


Figure 6. Model used to calculate *C* for the fabric face: (left) adhesive interlining surface and (right) fabric face surface

Experimental

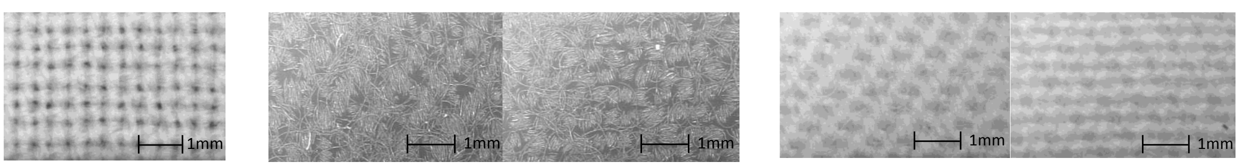
The shear stiffness values of face fabrics, adhesive interlinings and laminated fabrics were measured using a KES-FB1 shear tester (Katotech Co.) [15]. The shear stiffness value (*G*, the shear force per unit length / shear degree) was used as a measure of shear stiffness. Each test was carried out in the standard conditions (temperature of 20 ± 1 °C and relative humidity of 65 ± 5%) and all samples were equilibrated to the standard conditions for 24 h prior to testing. Five replicates were performed of each test and the results were averaged.

One plain face fabric, two twill fabrics and two satin fabrics with different weft weave densities and 24 plain adhesive interlinings (warp and weft weave density of 38 × 25 cm^{-1}) were prepared as test samples. The surfaces of the face fabrics are shown in Figure 7 and the sample specifications are summarized in Tables 1 and 2. Thickness was measured using KES-FB3 [15]. The adhesive agents used in all adhesive interlinings were of dot type and were randomly distributed over a base cloth of 100% polyester. The number, diameter and mass of adhesive dots were changed and applied to the same cloth sample. A1 and A2 groups are that interlinings have the same diameter and different adhesive mass (small mass group, 1 and large mass group, 2). A, B and C are different adhesive dot numbers. A total of 96 laminated fabric samples were examined for various combinations of conditions. The interlinings were bound to the face fabrics automatically by a press machine (Kobe Denki Kogyosyo, BP-V4812D) operating at 150 °C and applying a load of 0.3 kgf/cm² for 10 s. Additional samples of face fabrics and adhesive interlinings were also prepared in this study. Those were pressed under the same bonding conditions applied when laminating the adhesive interlining to the face fabric. Adhesive interlining samples were combined with polytetrafluoroethylene film (Nitto, No. 900, 0.05 × 300 mm) to allow pressing of the adhesive in the absence of fabric. Adhesive interlinings were thus bonded to polytetrafluoroethylene films, which were subsequently removed. *IR* values of the face fabrics were obtained using equation (21).

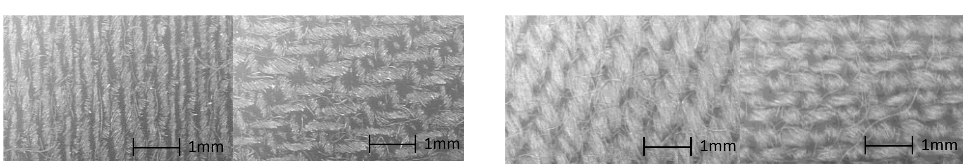
The ratio of yarn interlacing points (*C*) was determined from photographs of adhesive interlinings and face fabrics obtained with a microscope (Figure 6). The size of each image was 3 mm × 3 mm. The placement of adhesive dots on interlining was counted from the interlining image. The placement of adhesive dots on the face fabric was then supposed from the placement of dots on the interlining. A fixed number of interlacing points on the face fabric was counted from the image of the face fabric superposed with the placement of dots as shown in Figure 6. A fixed number of adjacent yarns were included. The means of counts made in three areas were used. The relationships among *C*, *IR* and *M* were subsequently investigated employing the proposed model. In addition, equation (22) was verified experimentally.

Table 1. Face fabric specifications

Sample name	**Structure**	**Yarn count (warp, weft)**	**Density/cm(/inch) (warp × weft)**	**Material**	**Weight (g/m^2)**	**Thickness (mm)**	**Shear stiffness (gf/(cm × degree))**
Plain	plain	28 tex, 28 tex	26×23 (66×58)	Wool 100%	135	0.40	0.63
Twill 1	twill	19 tex×2, 19 tex×2	31×25 (79×64)	Wool 100%	195	0.66	0.78
Twill 2	twill	19 tex×2, 28 tex	36×28 (91×71)	Wool 100%	192	0.46	0.90
Satin 1	satin	28tex, 28tex	48×26 (122×66)	Wool 100%	189	0.55	0.51
Satin 2	satin	34tex, 32tex	32×28 (81×71)	Wool 100%	218	0.61	0.75



(a) Plain (b) Twill 1 (face) (c) Twill 1 (back) (d) Twill 2 (face) (e) Twill 2 (back)



(f) Satin 1 (face) (g) Satin 1 (back) (h) Satin 2 (face) (j) Satin 2 (back)

Figure 7. Photographs of face fabric samples

Table 2. Adhesive interlining specifications

Group	Sample name	Adhesive dot number (/cm^2)	Adhesive diameter (µm)	Adhesive mass (g/m^2)
A1	A1-1	82	0.12	4.9
	A1-2		0.19	6.5
	A1-3		0.26	8.2
	A1-4		0.34	10.3
A2	A2-1		0.12	9.2
	A2-2		0.19	10.0
	A2-3		0.26	13.1
	A2-4		0.34	13.9
B1	B1-1	105	0.11	5.7
	B1-2		0.17	6.3
	B1-3		0.23	8.6
	B1-4		0.30	11.1
B2	B2-1		0.11	10.0
	B2-2		0.17	10.2
	B2-3		0.23	12.9
	B2-4		0.30	13.5
C1	C1-1	121	0.10	6.1
	C1-2		0.16	7.3
	C1-3		0.21	9.3
	C1-4		0.28	11.7
C2	C2-1		0.10	10.3
	C2-2		0.16	11.7
	C2-3		0.21	14.8
	C2-4		0.28	13.9

Results and discussion

Relationship between the ratio of fixed interlacing points and adhesive mass

The numbers of fixed interlacing points and adjacent yarns as a function of adhesive mass for each fabric are shown in Figure 8. As adhesive mass increased, the numbers of fixed interlacing points and adjacent yarns also increased. The numbers for Twill 1 and Twill 2 were different and the numbers for Satin 1 and Satin 2 were different even though the structure was the same. The difference in numbers of fixed interlacing points and adjacent yarns was due to the different yarn counts and weave densities. For the fabrics, there was an increase in the ratio of the number of fixed points in the vicinity of adhesive mass of 10 g/m^2. *C* (percentage of interlacing points that are fixed) as a function of adhesive mass for each fabric is shown in Figure 9. The increase in *C* with adhesive mass was similar to the increase in the number of fixed interlacing points in Figure 8. Similar to the relation in Figure 8, there was an increase in the ratio of the number of fixed points in the vicinity of 10 g/m^2.

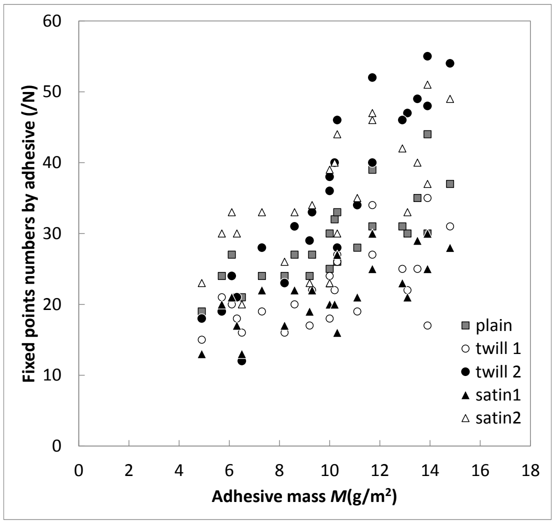


Figure 8. Numbers of fixed interlacing points and adjacent yarns as a function of the adhesive dot mass for each fabric

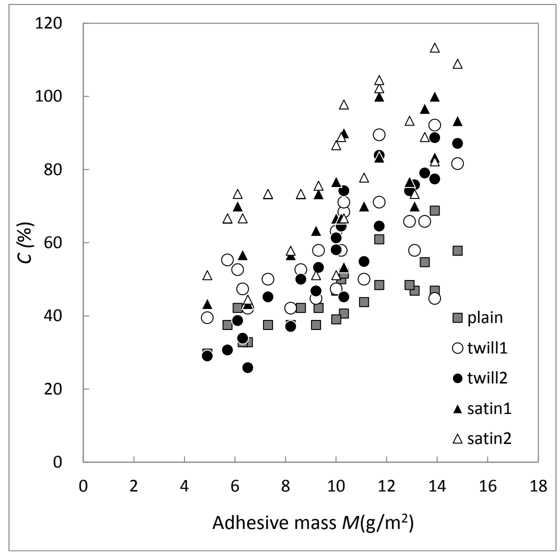


Figure 9. C (fixed number / all interlacing number %) as a function of the adhesive dot mass for each fabric

Figure 10 shows *IR* as the function of the number of fixed interlacing points and adjacent yarns for each fabric. Even for the same fixed interlacing points, *IR* differed for each face fabric. Figure 11 shows *IR* as the function of *C* for each fabric. As seen for the results in Figure 10, even with the same *C*, *IR* differed for each face fabric. Because the points of fixed parallel yarns were included in the counting of *C*, *C* exceeded 100% for twill and satin fabrics. It is thus necessary to adopt the effect of fixed parallel yarns.

According to the results of previous study [14] for the plain fabric, as the weave density of the face fabric increases, the shear stiffness values of laminated fabrics with the same adhesive interlining also increase. A comparison of Twill 1 and Twill 2 shows that the two fabrics have a similar yarn count and Twill 2 has the higher weave density and *IR*. The interlacing points of woven fabrics thus affect the shear stiffness of the face fabric after bonding. In the case of satin samples, however, the Satin-1 material having fewer interlacing points has the lower *IR* value than Satin 2, and the density of Satin 1 is higher than that of Stain 2. Although both satin fabrics had the same basic structure, their yarn counts and weave densities were different and our results thus reveal that both the yarn count and weave density affect the shear stiffness of laminated fabrics.

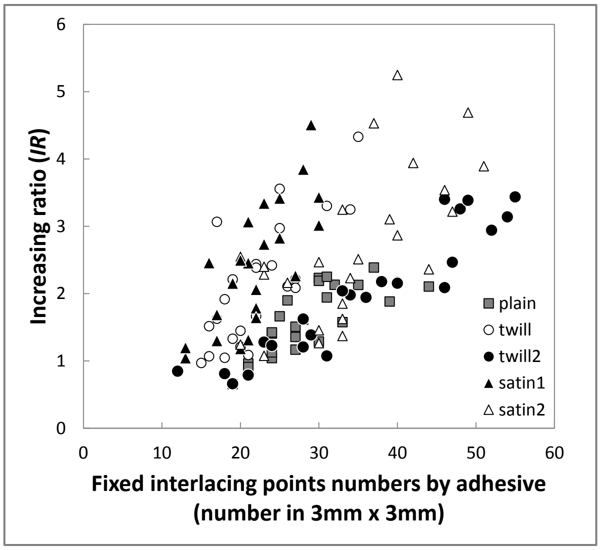


Figure 10. *IR* as a function of fixed interlacing points and adjacent yarn numbers for each fabric

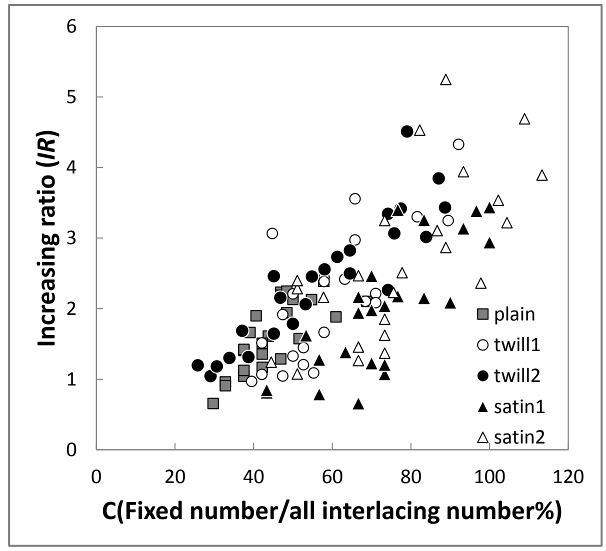


Figure 11. *IR* as a function of *C* for each fabric

Figure 12 shows *IR* as a linear function of the adhesive mass for each fabric. Coefficient of determination adjusted for the degrees of freedom, $\bar{r}^2$ of Adhesive mass and increasing ration for face fabrics are shown in Table 3. Even though *C* is taken into account the effect of weave density, the relationship between *IR* and adhesive mass is more linear than the relationship between *C* and adhesive mass. It is thought that the counted *C* values have a large margin of error owing to the enumeration. The count of fixed points is a discrete value. Partially attached adhesive agent also affects the shear stiffness of the laminated fabric. The counts were too small to reveal the overall effect of adhesive including the effect of partially attached adhesive. It was experimentally found that the adhesive mass provided the entire effect with the less error. Therefore, *IR* can be expressed as a function of adhesive mass *M* as shown in equation (21). The relationships are linear and we can thus obtain a linear regression equation for each face fabric using a small number of interlinings. Therefore, we can predict *IR* using the adhesive mass and the regression equation.

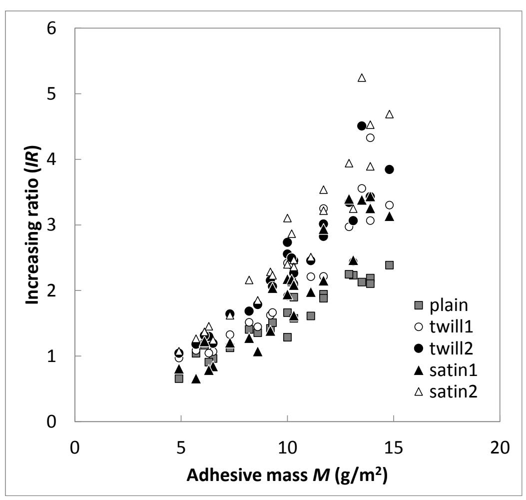


Figure 12. *IR* as the function of adhesive mass for each fabric

Table 3 Coefficient of determination adjusted for the degrees of freedom, $\bar{r}^2$ of Adhesive mass and *IR* for face fabrics

Face fabric	Plain	Twill1	Twill2	Satin1	Satin 2
$\bar{r}^2$	0.89	0.84	0.91	0.88	0.88

Prediction of shear stiffness for laminated fabric

We obtained regression equations for face fabrics using four samples depending on interlining groups and face fabrics). Regression equations for $IR=aM+b$ and those coefficient of determination adjusted for the degrees of freedom, $\bar{r}^2$ depending on face fabrics and interlining groups are shown in Table 4. P values Pa and Pb for coefficients a and b are also shown in Table 4. Using the equations and the adhesive mass M, we obtained IR for other samples. The experimental IR values for each laminated fabric and those calculated ones using the regression equations for each interlining group are shown in Table 5. The shear stiffness values of the other samples were then calculated using IR in the conjunction with equation (22). The calculated shear stiffness using an equation from plain and A1 group are shown in Figure 13. The calculated shear stiffness values for the plain samples were in good agreement with the experimental data. The results were the same as those obtained in the previous study [14]. In the case of the twill and satin samples, however, there were significant prediction errors for relatively large shear stiffness values.

Table 4 Regression equations for $IR=aM+b$, those coefficient of determination adjusted for the degrees of freedom, $\bar{r}^2$ depending on face fabrics and interlining groups and P values P_a and P_b for coefficients a and b

Face fabric	Parameter	Interlining group					
		A1	A2	B1	B2	C1	C2
Plain	a	0.2336	0.1695	0.1234	0.1564	0.1495	0.1645
	b	- 0.5161	- 0.0814	0.2504	0.1258	0.1491	- 0.0987
	$\bar{r}^2$	0.9958	0.9325	0.9196	0.1077	0.9047	0.9436
	P_a	0.0013	0.8144	0.0410	0.3635	0.0322	0.0190
	P_b	0.0167	0.022	0.3585	0.9436	0.6030	0.7692
Twill1	a	0.2181	0.2647	0.2137	0.2902	0.1823	0.3332
	b	- 0.2164	- 0.7968	- 0.2464	- 0.5487	0.0353	- 0.9824
	$\bar{r}^2$	0.9248	0.8852	0.9234	0.8529	0.9718	0.3321
	P_a	:0.0254	0.0390	0.0289	0.0503	0.0094	0.2551
	P_b	0.5129	0.3341	0.4819	0.5616	0.8441	0.7510
Twill2	a	0.2681	0.237	0.235	0.4476	0.265x	0.322
	b	- 0.4088	0.0598	- 0.183	- 1.9453	- 0.319	- 0.9427
	$\bar{r}^2$	0.9256	0.9400	0.9937	0.7142	0.9882	0.9350
	P_a	0.0251	0.0202	0.0021	0.1002	0.0039	0.2677
	P_b	0.3470	0.8952	0.1757	0.3938	0.1629	0.0219
Satin1	a	0.1612	0.3283	0.2352	0.3854	0.1919	0.2423
	b	- 0.067	- 1.5306	- 0.7394	- 1.708	0.0048	- 0.1712
	$\bar{r}^2$	0.9089	0.8496	0.9130	0.9650	0.7790	0.6021
	P_a	0.0308	0.0514	0.0294	0.0117	0.0765	0.1428
	P_b	0. 7933	0.2340	0.1605	0.0746	P0.9932	0.9084
Satin2	a	0.2835x	0.4158	0.2228	0.546	0.3876	0.4752
	b	- 0.3834	- 1.6882	0.0032	- 2.5712	- 1.144	- 2.4835
	$\bar{r}^2$	0.8880	0.7766	0.9863	0.7636	0.9461	0.9518
	P_a	0.0380	0.0774	0.0046	0.0822	0.0181	0.0162
	P_b	0.4760	0.3622	0.9818	0.3204	0.1347	0.0869

Table 5 Experimental IR (IR_E) and Calculated IR (IR_C) for each laminated sample

Face fabric / Interlining	Plain							Twill 1							Twill 2						
	IR_E	IR_C						IR_E	IR_C						IR_E	IR_C					
		P-A1	P-A2	P-B1	P-B2	P-C1	P-C2		T1-A1	T1-A2	T1-B1	T1-B2	T1-C1	T1-C2		T2-A1	T2-A2	T2-B1	T2-B2	T2-C1	T2-C2
A1-1	0.65	0.63	0.75	0.86	0.89	0.88	0.71	0.97	0.85	0.50	0.80	0.87	0.93	0.65	1.04	0.90	1.22	0.97	0.25	0.98	0.64
A1-2	0.96	1.00	1.02	1.05	1.14	1.12	0.97	1.07	1.20	0.92	1.14	1.34	1.22	1.18	1.19	1.33	1.60	1.34	0.96	1.40	1.15
A1-3	1.41	1.40	1.31	1.26	1.41	1.38	1.25	1.51	1.57	1.37	1.51	1.83	1.53	1.75	1.68	1.79	2.00	1.74	1.73	1.85	1.70
A1-4	1.90	1.89	1.66	1.52	1.74	1.69	1.60	2.11	2.03	1.93	1.95	2.44	1.91	2.45	2.46	2.35	2.50	2.24	2.66	2.41	2.37
A2-1	1.42	1.63	1.48	1.39	1.56	1.52	1.41	1.62	1.79	1.64	1.72	2.12	1.71	2.08	2.15	2.06	2.24	1.98	2.17	2.12	2.02
A2-2	1.66	1.82	1.61	1.48	1.69	1.64	1.55	1.92	1.96	1.85	1.89	2.35	1.86	2.35	2.56	2.27	2.43	2.17	2.53	2.33	2.28
A2-3	2.23	2.54	2.14	1.87	2.17	2.11	2.06	2.44	2.64	2.67	2.55	3.25	2.42	3.38	3.06	3.10	3.16	2.90	3.92	3.15	3.28
A2-4	2.19	2.73	2.27	1.97	2.30	2.23	2.19	3.06	2.82	2.88	2.72	3.49	2.57	3.65	3.42	3.32	3.35	3.08	4.28	3.36	3.53
B1-1	1.04	0.82	0.88	0.95	1.02	1.00	0.84	1.09	1.03	0.71	0.97	1.11	1.07	0.92	1.18	1.12	1.41	1.16	0.61	1.19	0.89
B1-2	0.91	0.96	0.99	1.03	1.11	1.09	0.94	1.05	1.16	0.87	1.10	1.28	1.18	1.12	1.30	1.28	1.55	1.30	0.87	1.35	1.09
B1-3	1.35	1.49	1.38	1.31	1.47	1.43	1.32	1.45	1.66	1.48	1.59	1.95	1.60	1.88	1.78	1.90	2.10	1.84	1.90	1.96	1.83
B1-4	1.61	2.08	1.80	1.62	1.86	1.81	1.73	2.21	2.20	2.14	2.13	2.67	2.06	2.72	2.45	2.57	2.69	2.43	3.02	2.62	2.63
B2-1	1.29	1.82	1.61	1.48	1.69	1.64	1.55	2.42	1.96	1.85	1.89	2.35	1.86	2.35	2.73	2.27	2.43	2.17	2.53	2.33	2.28
B2-2	2.13	1.87	1.65	1.51	1.72	1.67	1.58	2.38	2.01	1.90	1.93	2.41	1.89	2.42	2.50	2.33	2.48	2.21	2.62	2.38	2.34
B2-3	2.25	2.50	2.11	1.84	2.14	2.08	2.02	2.97	2.60	2.62	2.51	3.19	2.39	3.32	3.34	3.05	3.12	2.85	3.83	3.10	3.21
B2-4	2.13	2.64	2.21	1.92	2.24	2.17	2.12	3.56	2.73	2.78	2.64	3.37	2.50	3.52	4.51	3.21	3.26	2.99	4.10	3.26	3.40
C1-1	1.17	0.91	0.95	1.00	1.08	1.06	0.90	1.21	1.11	0.82	1.06	1.22	1.15	1.05	1.31	1.23	1.51	1.25	0.79	1.30	1.02
C1-2	1.12	1.19	1.16	1.15	1.27	1.24	1.10	1.33	1.38	1.14	1.31	1.57	1.37	1.45	1.64	1.55	1.79	1.53	1.32	1.62	1.41
C1-3	1.51	1.66	1.49	1.40	1.58	1.54	1.43	1.66	1.81	1.66	1.74	2.15	1.73	2.12	2.06	2.08	2.26	2.00	2.22	2.15	2.05
C1-4	1.94	2.22	1.90	1.69	1.96	1.90	1.83	2.21	2.34	2.30	2.25	2.85	2.17	2.92	2.82	2.73	2.83	2.57	3.29	2.78	2.82
C2-1	1.57	1.89	1.66	1.52	1.74	1.69	1.60	2.08	2.03	1.93	1.95	2.44	1.91	2.45	2.26	2.35	2.50	2.24	2.66	2.41	2.37
C2-2	1.88	2.22	1.90	1.69	1.96	1.90	1.83	3.25	2.34	2.30	2.25	2.85	2.17	2.92	3.01	2.73	2.83	2.57	3.29	2.78	2.82
C2-3	2.39	2.94	2.43	2.08	2.44	2.36	2.34	3.30	3.01	3.12	2.92	3.75	2.73	3.95	3.84	3.56	3.57	3.30	4.68	3.60	3.82
C2-4	2.10	2.73	2.27	1.97	2.30	2.23	2.19	4.33	2.82	2.88	2.72	3.49	2.57	3.65	3.43	3.32	3.35	3.08	4.28	3.36	3.53

Face fabric / Interlining	Satin 1							Satin 2						
	IR_E	IR_C						IR_E	IR_C					
		S1-A1	S1-A2	S1-B1	S1-B2	S1-C1	S1-C2		S2-A1	S2-A2	S2-B1	S2-B2	S2-C1	S2-C2
A1-1	0.81	0.72	0.08	0.41	0.18	0.95	1.02	1.07	1.01	0.35	1.09	0.10	0.76	0.16
A1-2	0.85	0.98	0.60	0.79	0.80	1.25	1.40	1.24	1.46	1.01	1.45	0.98	1.38	0.61
A1-3	1.28	1.25	1.16	1.19	1.45	1.58	1.82	2.16	1.94	1.72	1.83	1.91	2.03	1.41
A1-4	1.62	1.59	1.85	1.68	2.26	1.98	2.32	2.47	2.54	2.59	2.30	3.05	2.85	2.41
A2-1	1.38	1.42	1.49	1.42	1.84	1.77	2.06	2.28	2.22	2.14	2.05	2.45	2.42	1.89
A2-2	1.94	1.55	1.75	1.61	2.15	1.92	2.25	2.40	2.45	2.47	2.23	2.89	2.73	2.27
A2-3	2.46	2.04	2.77	2.34	3.34	2.52	3.00	3.25	3.33	3.76	2.92	4.58	3.93	3.74
A2-4	3.26	2.17	3.03	2.53	3.65	2.67	3.20	4.53	3.56	4.09	3.10	5.02	4.24	4.12
B1-1	0.66	0.85	0.34	0.60	0.49	1.10	1.21	1.26	1.23	0.68	1.27	0.54	1.07	0.23
B1-2	0.79	0.95	0.54	0.74	0.72	1.21	1.36	1.45	1.40	0.93	1.41	0.87	1.30	0.51
B1-3	1.07	1.32	1.29	1.28	1.61	1.66	1.91	1.85	2.05	1.89	1.92	2.12	2.19	1.60
B1-4	1.98	1.72	2.11	1.87	2.57	2.13	2.52	2.51	2.76	2.93	2.48	3.49	3.16	2.79
B2-1	2.18	1.55	1.75	1.61	2.15	1.92	2.25	3.10	2.45	2.47	2.23	2.89	2.73	2.27
B2-2	2.17	1.58	1.82	1.66	2.22	1.96	2.30	2.87	2.51	2.55	2.28	3.00	2.81	2.36
B2-3	3.40	2.01	2.70	2.29	3.26	2.48	2.95	3.94	3.27	3.68	2.88	4.47	3.86	3.65
B2-4	3.38	2.11	2.90	2.44	3.49	2.60	3.10	5.25	3.44	3.93	3.01	4.80	4.09	3.93
C1-1	1.23	0.92	0.47	0.70	0.64	1.18	1.31	1.37	1.35	0.85	1.36	0.76	1.22	0.42
C1-2	1.21	1.11	0.87	0.98	1.11	1.41	1.60	1.62	1.69	1.35	1.63	1.41	1.69	0.99
C1-3	2.04	1.43	1.52	1.45	1.88	1.79	2.08	2.23	2.25	2.18	2.08	2.51	2.46	1.94
C1-4	2.15	1.82	2.31	2.01	2.80	2.25	2.66	3.54	2.93	3.18	2.61	3.82	3.39	3.08
C2-1	2.09	1.59	1.85	1.68	2.26	1.98	2.32	2.36	2.54	2.59	2.30	3.05	2.85	2.41
C2-2	2.94	1.82	2.31	2.01	2.80	2.25	2.66	3.22	2.93	3.18	2.61	3.82	3.39	3.08
C2-3	3.14	2.32	3.33	2.74	4.00	2.84	3.41	4.69	3.81	4.47	3.30	5.51	4.59	4.55
C2-4	3.44	2.17	3.03	2.53	3.65	2.67	3.20	3.89	3.56	4.09	3.10	5.02	4.24	4.12

*P-A1 means calculated *IR* using regression equation obtained using plain face fabric P and interlining group A1.

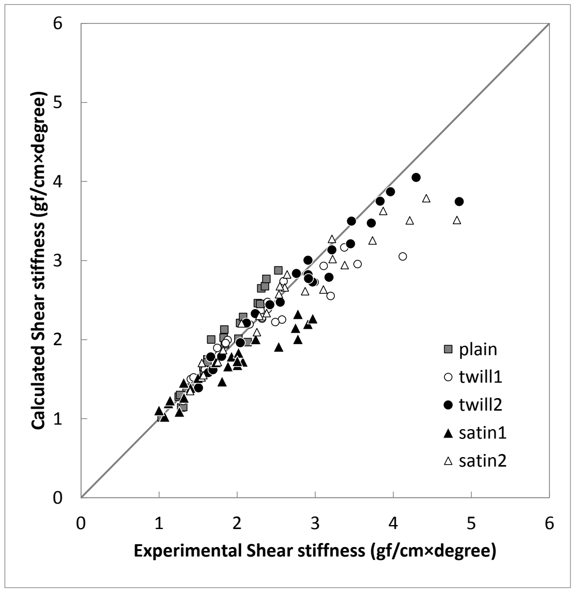


Figure 13. Comparison of calculated and experimental shear stiffness values for laminated fabrics, incorporating a regression equation for the A1-1 samples

Figure 14 shows that two or more interlacing points may be affixed by each dot when the mass of the adhesive dots becomes large. In addition, the adhesive dots may fix pairs of adjacent parallel yarns. Therefore, we divide the adhesive mass range into two sections for the purposes of estimating *IR* and predicting shear stiffness.

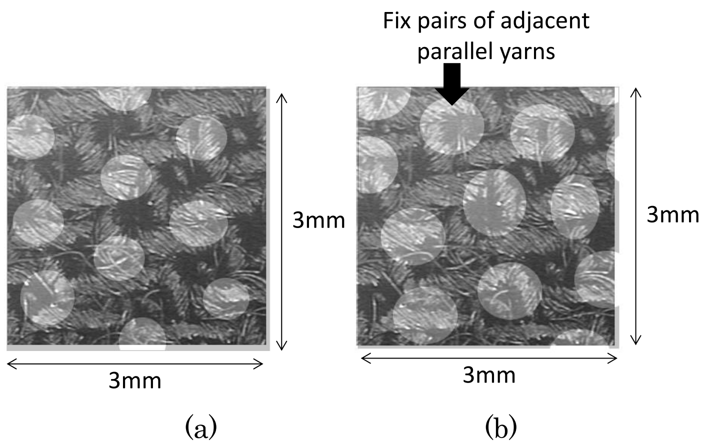
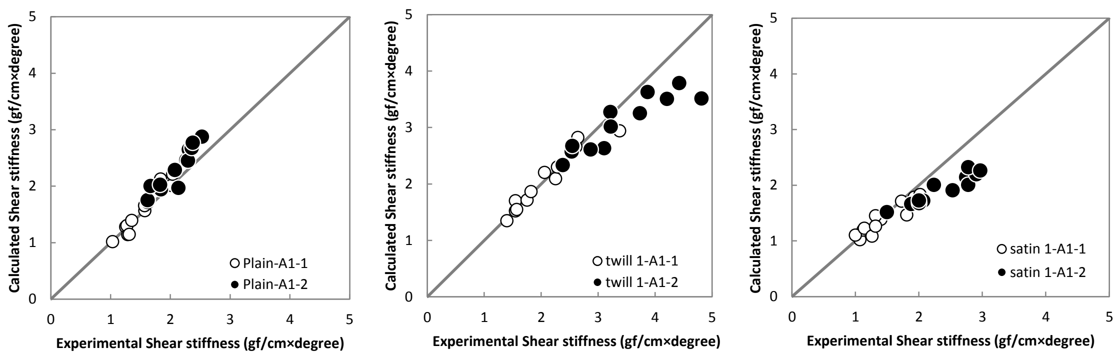


Figure 14. Surface pictures of Twill 1 superposing the adhesive dot area of (a) the B1-4 interlining and (b) the B2-4 interlining

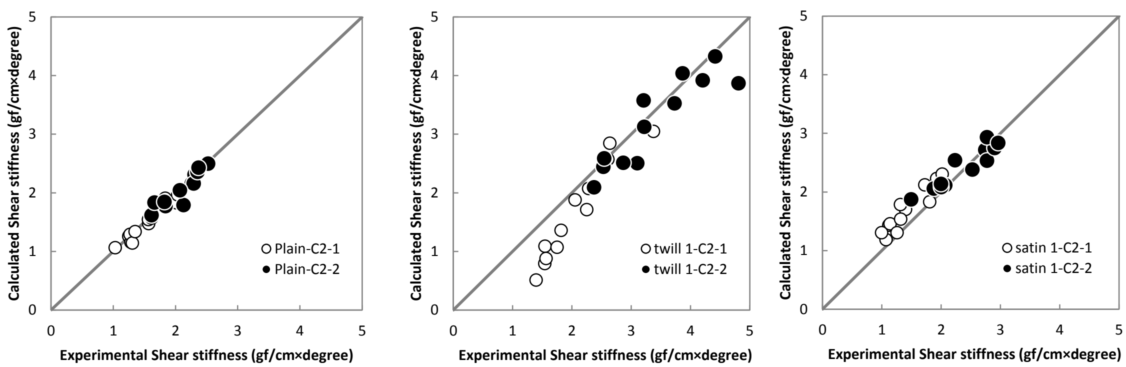
Figures 15 and 16 compare calculated and experimental shear stiffness values obtained using regression equations derived for the A1 and C2 sample groups of Plain, Twill-1 and Satin-1 fabrics. In the case of the plain samples, as shown in Figure 15 (a) and Figure 16 (a), the regression equation produces results similar to the predicted values. In the case of the Twill-1 and Satin-1 fabrics, however, the data points do not conform exactly to the line of the regression equation. These results demonstrate that it is necessary to consider the effects of floating yarns when predicting the shear stiffness of laminated fabrics.

When making adhesive, we controlled adhesive mass as keeping the size of adhesive diameter. Thus, we obtained interlinings which have the same diameter and different mass (small mass group and large mass group). We considered the effect of adhesive mass in the same dot diameter. Thus we further divided the samples into two groups representing larger and smaller adhesive interlining masses to obtain the regression equation for *IR* with *M*. For prediction purposes, we used the C1 data for smaller interlining masses and the C2 data for larger masses. The predicted shear stiffness values of laminated fabrics using both equations are portrayed in Figure 17. The mean absolute percentage error (MAPE) of the predicted shear stiffness values and the particular regression equations used are summarized in Table 6. As shown in Figure 17 and Table 6, the predictions obtained using the two equations are in better agreement with the experimental data. In conclusion, we found that the shear stiffness of woven fabrics is affected by the adhesive fixing of adjacent floating yarns in addition to the fixing of interlacing points.



(a) Plain (b) Twill 1 (c) Satin 1

Figure 15. Comparison of calculated and experimental shear stiffness values for plain fabrics, incorporating the regression equations obtained for the A1 samples and each face fabric
Legend: white dot = smaller mass group, black dot = larger mass group



(a) Plain (b) Twill 1 (c) Satin 1

Figure 16. Comparison of calculated and experimental shear stiffness values for plain fabrics, incorporating the regression equations obtained for the C2 samples and each face fabric
Legend: white dot = smaller mass group, black dot = larger mass group

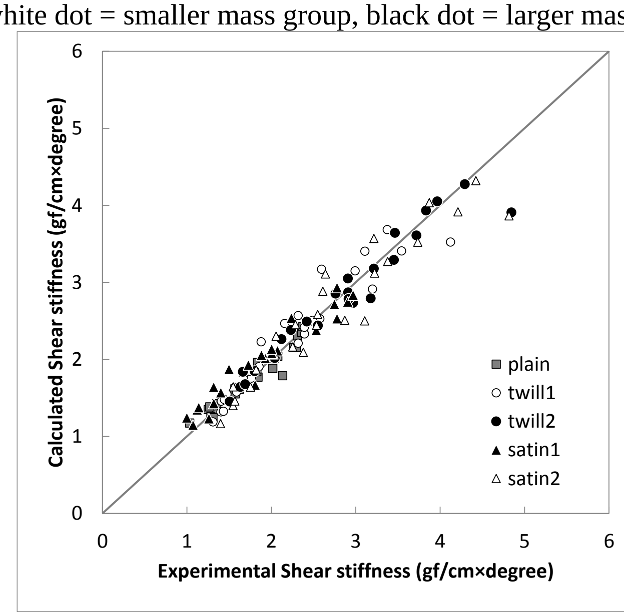


Figure 17. Comparison of calculated and experimental shear stiffness values of laminated fabrics, incorporating two regression equations

Table 6. MAPE of predicted shear stiffness values

Calculation type \ Sample	MAPE (%)				
	Plain	Twill 1	Twill 2	Satin 1	Satin 2
A1	4.1	9.7	7.2	13.3	14.8
Separated C1 and C2	1.2	6.3	5.5	3.4	9.6

5. Conclusions

This study proposed the shear model for laminated fabrics that takes into account the effect of adhesive dot-type. A prediction method was also formulated and verified for plain, twill and satin fabrics experimentally. It was revealed that the shear stiffness of laminated fabrics is affected by the adhesive fixing of adjacent floating yarns in addition to the fixing of interlacing points. It was experimentally found that the effect was provided by the mass of the adhesive agent. It was possible to predict the shear stiffness of laminated fabrics made of the same material but produced under different adhesive conditions, from the adhesive mass and *IR* obtained experimentally for a small number of samples. The shear stiffness values of laminated fabrics were predicted more precisely by dividing the regression area according to the mass of adhesive applied during interlining. This study targeted the dot type adhesive with woven fabric. Thus, the proposed method is suitable for them. The possibility of the proposed method for another type of adhesive and fabric will be our future study.

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