



CHANGES IN INTERLINING FABRIC PROPERTIES DURING FUSING AND A STUDY OF ADHESION STRENGTH

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Abstract. The physical and mechanical properties of fused assemblies were determined; the analysis of changes in air permeability and areal density made it possible to predict them in advance with a known standard deviation. It was found that adhesion is statistically independent of the raw fabric structure and that the levers for controlling it lie at the adhesive coating and fusing stage — adhesive dot density, areal density of the shell fabric and interlining, and fusing conditions; the effect of weave also acts through the interaction of the interlining surface relief with the adhesive dots.

Keywords: fused assembly, garment interlining, shell fabric, standard deviation, breaking force, areal density, air permeability, indicator, adhesive coating, adhesive dot.

Introduction. Requirements for interlining fabrics fall into two groups: requirements for the interlining itself (areal density, thickness, stiffness, shrinkage) and for the adhesive bond (adhesion strength, resistance to dry cleaning and washing) [1]. Standard technical requirements by garment type are summarized in Table 1.

Table 1

Technical requirements and test methods for interlining fabrics by garment type

No.	Indicator	Coat	Suit	Raincoat	Test method
1	Areal density, g/m ²	180–200	140–180	100–120	GOST 3811-72
2	Thickness (at 196 Pa pressure), mm	0.5–0.8	0.4–0.6	0.4–0.6	GOST 12023-2003
3	Bending stiffness, μN·cm ²	2000–7000	1000–5000	1000–2000	GOST 10550-93
4	Shrinkage after wetting, %, max	2.0	2.0	2.0	GOST 30157.0-95
5	Shrinkage after wet-heat treatment, %, max	1.5	1.5	—	OST 17-790-85
6	Adhesive bond strength, N/cm, min	3.0	3.0	3.0	GOST 28832-90
7	Resistance of the bond to dry cleaning, %, min	70–75	70–75	—	GOST 28832-90
8	Resistance of the bond to washing, %, min	—	—	80	GOST 28832-90

Table 1 was compiled from the data of [2–5]. Several remarks should be made regarding Table 1. First, the literature gives different values for adhesive bond strength: the TsNIIShP requirements (Russian: Требования ЦНИИШП — the scientific and technical requirements for garment design, modeling and size standards in the garment industry) specify at least 3.0 N/cm for outerwear and 2.0–



2.5 N/cm for shirts and blouses [6], whereas the table given in our PhD dissertation and in the 2023 article states this value as 0.35 N/cm. The latter value is almost eight times lower than current industry requirements and may be due to a difference in units or measurement scheme; in this study, 3.0 N/cm is taken as the lower limit for bond strength. Second, the stiffness requirements are given over a very wide range (1000–5000 $\mu\text{N}\cdot\text{cm}^2$ for suits, i.e., fivefold), which indicates the need for differentiated requirements for different garment parts (front, collar, lapel). Third, no requirements are set for the air permeability and strength of the interlining itself, although the hygienic properties of the fused assembly depend precisely on the interlining and the adhesive coating.

The TsNIIShP requirements for woven thermo-adhesive interlinings are even more differentiated. For interlinings for lapels, vests and small parts, an areal density of 80–90 g/m^2 , a thickness of 0.6 ± 0.05 mm, and a stiffness of up to 2500 $\mu\text{N}\cdot\text{cm}^2$ in the warp and 900 $\mu\text{N}\cdot\text{cm}^2$ in the weft are specified; for edge tapes for suits and coats, 80–95 g/m^2 and a stiffness of 1000–1200 in the warp and 500–700 $\mu\text{N}\cdot\text{cm}^2$ in the weft [6]. Multi-zone interlinings require 175–200 g/m^2 and 25,000–35,000 $\mu\text{N}\cdot\text{cm}^2$ in the warp and 2000–5000 $\mu\text{N}\cdot\text{cm}^2$ in the weft for the stiff zone, 150–170 g/m^2 and 10,000–17,000 / 1000–3000 $\mu\text{N}\cdot\text{cm}^2$ for the transition zone, and 120–140 g/m^2 and 2000–5000 / 1000–2000 $\mu\text{N}\cdot\text{cm}^2$ for the soft zone. For frontal fusing of suit and coat fronts, woven interlinings with an areal density of 100–140 g/m^2 and a stiffness of 1500–6000 $\mu\text{N}\cdot\text{cm}^2$ are used; the stiffness of imported knitted interlinings is 832–1786 $\mu\text{N}\cdot\text{cm}^2$ in the heavy variant and 392–1024 $\mu\text{N}\cdot\text{cm}^2$ in the light variant. For canvas interlinings (bortovka), GOST 5665-77 specifies an areal density of up to 370 g/m^2 , shrinkage after wetting of up to 3.5% in the warp and 2.5% in the weft, and a stiffness of 5–16 $\text{mN}\cdot\text{cm}^2$ [7].

Results. Physical and mechanical properties of fused assemblies. In a garment, the interlining works as part of a bonded assembly with the shell fabric, so its quality is ultimately assessed by the properties of the assembly [6, 8]. At DUBLIRIN LLC, a polyester + polyamide adhesive was applied to the raw fabrics through a mesh-25 screen (≈ 97 dots/ cm^2) in the form of hemispherical dots, and at Ideal Textil Orzu LLC the fabrics were fused with a suiting shell fabric on a Shengtian press at 150 $^{\circ}\text{C}$, 10 s and 0.3–0.5 kgf/cm^2 . Breaking properties were determined on two parallel specimens, and the adhesion (peel) strength on a Shimadzu AG-1 testing machine. The results and the changes relative to the raw fabric are given in Table 2.

Table 2

Properties of the assemblies fused with shell fabric and their changes relative to the raw fabric (in parentheses: for F , k = assembly/raw ratio; for Q , decrease, %; for M , increase, g/m^2)

No.	F_t , N (k_{Ft})	F_a , N (k_{Fa})	L_t , cm	L_a , cm	Q , $\text{dm}^3/(\text{m}^2\cdot\text{s})$ (decrease, %)	M , g/m^2 (ΔM)	P , N/cm
1	651.7 (2.63)	1195.7 (1.82)	2.33	4.55	55.8 (67.2)	479.2 (194.8)	20
2	339.9 (1.35)	1694.2 (2.66)	0.80	7.95	72.0 (94.3)	322.9 (220.1)	22
3	349.8 (1.33)	702.3 (1.72)	1.06	3.25	80.5 (93.7)	338.9 (219.1)	23
4	719.6 (2.91)	1180.8 (1.77)	2.84	4.66	51.5 (51.6)	453.6 (212.6)	20



No.	F_t , N (k_{Ft})	F_a , N (k_{Fa})	L_t , cm	L_a , cm	Q , $\text{dm}^3/(\text{m}^2 \cdot \text{s})$ (decrease, %)	M , g/m^2 (ΔM)	P , N/cm m
5	351.1 (1.23)	1569.1 (2.22)	0.85	8.70	63.2 (85.8)	324.1 (222.4)	16
6	382.5 (1.28)	719.0 (1.52)	1.10	3.17	68.8 (89.6)	333.9 (214.9)	18
7	394.8 (1.29)	438.3 (1.54)	1.15	2.40	78.0 (93.3)	322.5 (214.3)	16
8	534.6 (1.90)	931.1 (1.92)	1.75	3.90	60.0 (95.5)	334.5 (212.6)	12
9	319.1 (1.11)	1623.1 (2.31)	0.49	8.77	46.4 (80.4)	322.3 (220.7)	17
10	506.9 (1.72)	627.8 (2.16)	1.60	3.10	73.2 (83.6)	316.5 (205.8)	14
11	690.0 (2.69)	1397.0 (2.92)	2.75	6.95	52.0 (52.9)	413.5 (208.2)	10
12	510.0 (1.88)	863.7 (1.46)	1.65	3.45	56.2 (71.7)	341.9 (213.5)	17
13	352.6 (1.25)	1095.2 (1.47)	0.91	8.10	40.1 (83.5)	306.2 (211.2)	9
14	589.1 (2.16)	664.2 (1.91)	2.02	3.00	72.0 (81.4)	327.5 (210.4)	5
15	743.2 (3.34)	841.8 (1.85)	3.45	3.60	56.4 (83.3)	412.2 (185.5)	14
16	362.2 (1.31)	1421.5 (2.21)	0.85	7.97	66.0 (93.0)	326.5 (229.6)	10
17	405.8 (1.36)	737.8 (1.62)	1.30	3.10	72.0 (94.2)	342.6 (214.1)	21
18	374.7 (1.22)	482.9 (1.64)	1.07	2.55	75.2 (94.8)	326.0 (210.8)	22
19	447.9 (1.53)	790.5 (1.48)	1.50	3.20	59.5 (88.8)	342.2 (210.9)	23
20	373.6 (1.25)	1330.2 (1.75)	0.96	6.80	57.0 (88.5)	312.3 (210.8)	17
21	438.8 (1.50)	552.5 (1.58)	1.35	3.00	66.0 (93.1)	334.8 (214.4)	16
Mean	468.5 (1.73)	993.3 (1.88)	1.51	4.86	63.0 (83.8)	349.2 (212.2)	16.3

The mean coefficient of variation of breaking force across parallel specimens is 4.7% (warp) and 6.2% (weft), i.e., the properties of the assemblies are more stable than those of the raw fabric: the adhesive dots fix the yarns at the crossover points and ensure that they take up the load simultaneously.

On fusing, breaking force increases on average by a factor of 1.725 in the warp and 1.882 in the weft (Figure 1, orange bars), but the degree of reinforcement differs by up to three times between variants. The greatest warp reinforcement occurs in the variants with PES 82 tex weft (2.63–3.34), and the smallest in those with PES 18 tex weft (1.11–1.35). As a result, variant 15, the weakest in the warp as raw fabric (222.8 N), becomes the strongest as an assembly (743.2 N); the correlation between the warp strength of the assembly and that of the raw fabric is negative ($r = -0.668$), while the correlation between assembly strength and the warp elongation of the raw fabric is strongly positive ($r = 0.926$). The mechanism lies in the deformation compatibility of the layers: under tension, the layers deform equally; if the elongation of the interlining is much lower than that of the shell fabric, the interlining breaks first and the strength of the assembly is limited by a single layer, whereas if the elongations

are similar, the layers carry the load jointly [9-11]. In the earlier PhD study, the high assembly strength of variant 15 was attributed to “the strength of the adhesive and the shell fabric”; re-analysis shows that it is due to the joint action of the layers owing to the high extensibility of the interlining. Thus, the high warp elongation, noted as a drawback of the raw fabric, becomes an advantage for the strength of the assembly. This also explains why the warp strength of plain-weave assemblies (530.7 N on average) is higher than that of twill and double-layer assemblies (444.0 and 414.0 N) ($\eta^2 = 0.072$; $p = 0.015$).

In the weft, the strength of the assembly correlates positively with that of the raw fabric ($r = 0.829$), since the PES 18 tex weft simultaneously gives the highest strength and elongation (1455.5 N on average in the assembly; 553.1 N for cotton-weft variants). For this indicator, the effect of Z is significant ($\eta^2 = 0.041$; $p = 0.040$) — the only such case among the assembly properties. Elongation at break decreases by 16% on average in the warp and increases by 27% in the weft; between raw-fabric and assembly elongations, $r = 0.950$ and 0.962 . The decrease in warp elongation is explained by the adhesive dots partially fixing the crimp waves of the warp, and the increase in the weft by the high extensibility of the shell fabric in the weft direction.

Changes in air permeability and areal density. Fusing reduces air permeability by 83.8% on average: in the assemblies it is 40.1–80.5 $\text{dm}^3/(\text{m}^2 \cdot \text{s})$ (Figure 4.3, right axis). The resistances of layers arranged in series in the air flow add up, and the densest layer — the shell fabric and adhesive layer — limits permeability [12, 13]; therefore, the 13.5-fold difference between the raw fabrics is reduced to at most twofold in the assemblies. The relationships between the properties of the raw fabric and the assembly are shown in Figure 1.

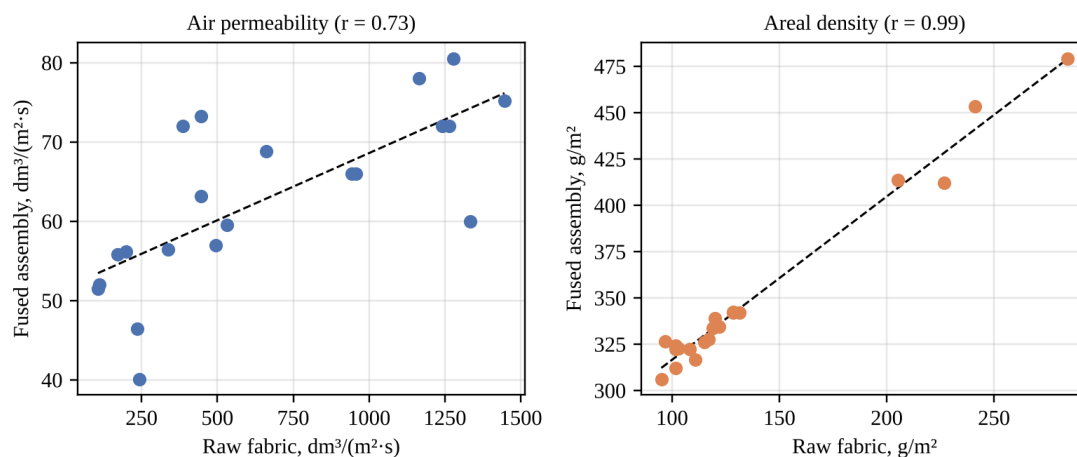


Figure 1. Relationship between the properties of the raw interlining fabric and the fused assembly

$$Q_{fus} = 51.67 + 0.0169 Q_{raw}, \quad r = 0.728, \quad p = 0.0002 \quad (1)$$

$$M_{fus} = 228.45 + 0.8816 M_{raw}, \quad r = 0.990 \quad (2)$$

where Q_{fus} , Q_{raw} are the air permeability of the assembly and the raw fabric, $\text{dm}^3/(\text{m}^2 \cdot \text{s})$; M_{fus} , M_{raw} are their areal densities, g/m^2 . The intercept in (1) reflects the “baseline” permeability of the assembly, and the small slope reflects the weakened influence of the interlining. The lowest permeability is found in plain-weave assemblies 13 and 9 with PES 18 tex weft (40.1 and 46.4), and the highest in assemblies 3, 7 and 18 (75.2–80.5 $\text{dm}^3/(\text{m}^2 \cdot \text{s})$). All assemblies meet the requirement of 20–100 $\text{dm}^3/(\text{m}^2 \cdot \text{s})$ for layered garment materials. The air permeability of the assembly is determined by the

weft yarn ($\eta^2 = 0.510$) and the weave ($\eta^2 = 0.272$); cotton-weft assemblies (72.9 on average) “breathe” better than PES-weft assemblies (53.9–57.5), which indicates the hygienic advantage of cotton and blended weft for suit fronts.

On fusing, areal density increases by 212.2 g/m² on average (2.72 times); the slope of less than one and the negative correlation of the mass gain with the areal density of the raw fabric ($r = -0.69$) show that the added mass of the shell fabric and adhesive is not constant; a probable cause is the stronger shrinkage of light, open-structure interlinings under heat and pressure (in the heavy variant 15 the increase is the smallest, 185.5 g/m²). The areal density of the raw interlining makes it possible to predict the mass of the assembly with a residual standard deviation of 6.8 g/m².

The experimentally determined adhesion strength values are shown in Figure 2.

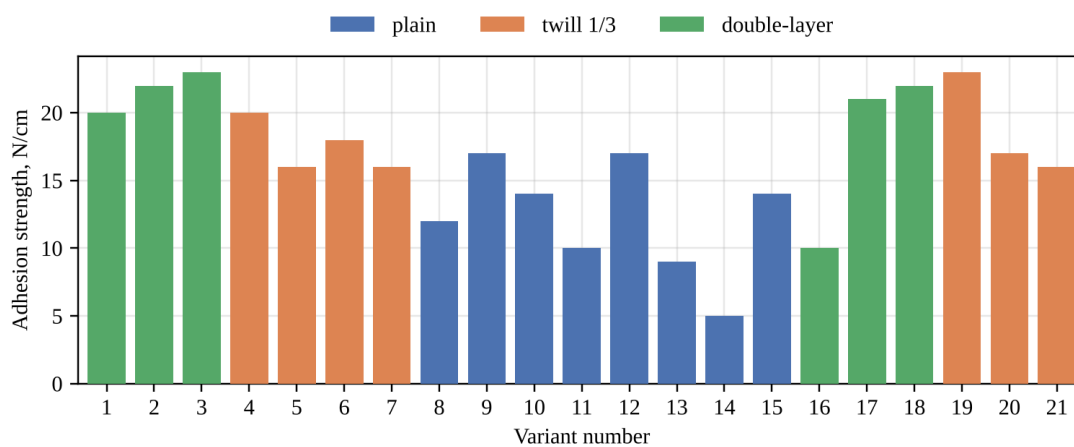


Figure 2. Adhesion (peel) strength of the interlining to the shell fabric

Adhesion varies from 5 N/cm (variant 14) to 23 N/cm (variants 3 and 19), with a mean of 16.3 N/cm; all variants exceed the minimum requirement for outerwear (at least 3.0 N/cm) [14, 15]. The highest values were obtained for variants 3, 19, 2, 18 and 17, which agrees with the conclusion of the earlier study on the superiority of variants 2, 3, 18 and 19 [16, 17].

The Spearman rank correlation of adhesion with the raw-fabric properties is not significant in any case: with air permeability $\rho = 0.31$ ($p = 0.17$), with areal density 0.273 ($p = 0.23$), with generalized stiffness 0.229 ($p = 0.32$), with B_t 0.254, with B_a -0.248 , with warp and weft elongation -0.251 and -0.137 , with weft linear density 0.195 ($p = 0.40$), and with PES proportion -0.05 ($p = 0.83$). Thus, the conclusion of the earlier work that “a polyester weft increases adhesion” [3] is not confirmed: the adhesion of variants 13 and 11 with 100% PES weft (9 and 10 N/cm) is half that of variant 18 with cotton weft (22 N/cm). This is consistent with adhesion theory: with dot coating, bond strength is determined mainly by the number and size of the adhesive dots, the flow and penetration depth of the melt, and the fusing temperature, pressure and time [6, 18–20].

Discussion. Analysis of variance revealed a significant effect of weave only ($F = 6.82$; $p = 0.0085$; $\eta^2 = 0.414$): 12.25 N/cm on average for plain-weave assemblies, and 18.00 and 19.67 N/cm for twill 1/3 and double-layer assemblies (Mann–Whitney test, $p = 0.005$). In twill and double-layer weaves, long weft floats form a flat, wide surface on which the adhesive dots rest, whereas in plain weave some of the dots fall into the hollows between the yarns or penetrate deeply, reducing the contact area with the shell fabric. At the same time, the model explains only a small part of the variance ($R_{adj}^2 =$

0.393), i.e., adhesion depends mainly on factors outside the weaving stage; other studies have also noted that adhesion is determined mainly by the type of adhesive coating and the fusing conditions, while the structure of the interlining base is a secondary factor [21, 22].

Re-evaluating the earlier recommendations in terms of assembly properties gives the following: variants 2, 3 and 18 are high in adhesion (22–23 N/cm) and air permeability (72.0–80.5), but only variants 2 and 18 have a stiffness (17.02 and 13.14 $\mu\text{N}\cdot\text{m}$) within the suit range, while that of variant 3 (9.48) is slightly below the lower limit; variant 15 (coat) is suitable in terms of stiffness and assembly strength, but its adhesion (14 N/cm) is below the mean. Since the best variants differ from one criterion to another, the final selection requires multi-criteria optimization.

The results of the study are of technological significance. They show that the technology can be optimized in two independent stages. Parameters at the weaving stage (weft linear density and fiber composition, weave) determine the stiffness, strength, extensibility, areal density and air permeability of the interlining and the assembly; these properties are highly correlated between the raw fabric and the assembly ($r = 0.73\text{--}0.99$) and can be predicted from the raw fabric. Adhesion, however, is statistically independent of the raw fabric structure, and the levers for controlling it lie at the adhesive coating and fusing stage — adhesive dot density, areal density of the shell fabric and interlining, and fusing conditions; the effect of weave also acts through the interaction of the interlining surface relief with the adhesive dots. Therefore, adhesion is optimized on the basis of a second-order regression model in terms of the adhesive coating parameters, while the nomogram and the relationships obtained provide a quantitative basis for selecting the weft yarn and calculating the generalized desirability function.

Conclusions. An important conclusion follows from these data: regulatory documents treat interlining stiffness as anisotropic and set separate requirements for the warp and weft directions, which often differ several-fold. For example, the warp-to-weft stiffness ratio is $2500/900 \approx 2.8$ for a lapel interlining and 7–12 for the stiff zone of a multi-zone interlining. Therefore, in interlining design, not only the generalized stiffness but also the degree of anisotropy should be a controlled parameter. This requirement provides a direct basis for selecting the fiber composition and linear density of the warp and weft systems separately, that is, for the concept of an interlining with different fiber compositions.

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