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Peel Strength of Silk and Nylon Textiles Adhered to Sheer Support Fabrics

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Abstract

Fabric laminates consisting of silk habutae or nylon taffeta artifacts, one of six adhesives (Acryloid F10, BEVA 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, or Vinamul 3252), and a support fabric (nylon net, polyester crepeline, or silk crepeline) were peeled at a rate of 50 mm min^{-1} in a controlled environment. The transfer of adhesive to the artifact fabric during peeling was observed visually and through scanning electron microscopy. The peel strength of the adhesives varied significantly according to the surface area of adhesive available for bonding and the mechanical properties of the adhesives. Bonds to silk habutae were stronger than bonds to nylon taffeta. Laminates supported on nylon net had weaker bonds than those supported on silk or polyester crepeline.

Titre et Résumé

Résistance au pelage d’échantillons textiles en soie et en nylon contrecollés à un tissu de renfort diaphane

Des essais de résistance au pelage ont été réalisés sur des substrats de tissus collés, composés d’objets en soie habutai ou en taffetas de nylon, d’un adhésif parmi une série de six (Acryloid F10, BEVA 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV ou Vinamul 3252) et d’un tissu de renfort (filet de nylon, crêpeline de polyester ou crêpeline de soie). Les essais ont exécutés dans des conditions ambiantes régulées et à une vitesse de pelage de 50 mm min^{-1}. Le transfert de l’adhésif à l’objet de tissu, durant le pelage, a été observé visuellement et au moyen d’un microscope électronique à balayage. La résistance au pelage des différents adhésifs varie grandement en fonction de leur surface de contact disponible et de leurs propriétés mécaniques. La force d’adhérence est supérieure dans le cas de la soie habutai que dans celui du taffetas de nylon. Les substrats de tissus contrecollés sur le filet de nylon présentent une force d’adhérence inférieure à ceux contrecollés sur la crêpeline de soie ou de polyester.

Introduction

Effective support for a textile artifact using an adhesive treatment requires a bond that will not fail under post-treatment display and handling conditions, but choosing an adhesive that will provide an adequate bond is complicated by the numerous factors that affect bond strength. Textile conservators often vary one or two aspects of adhesive treatments in their mock-up testing, such as support materials (Grant 1995), concentrations of a single adhesive (Hartog and

Tinker 1998), or different mixtures of two resins in different solvents (Thomsen 1984). When distinctly different adhesives are compared, however, a single preparation method for each — often based on past practice — is usually chosen (Grant 1995; Wills 1995). Similarly, when laboratory peel testing was used to develop a matrix to aid textile conservators in their choice of adhesive (Pretzel 1997a; Pretzel 1997b), comparative bond strength scores were derived from peel tests of one type of specimen per adhesive: silk habutae adhered to polyester crepeline using adhesive films produced from solutions of varying concentration (10–50% by volume). To better understand how adhesives contribute to bond strength, this study assessed the effects on peel strength of several different adhesives in laminates made with different artifact fabrics, support fabrics, and application techniques commonly used by textile conservators (Karsten 2003).

Methods

Preparation of laminated fabric specimens

Laminated fabric specimens were prepared from two artifact fabrics, three support fabrics, and six adhesives. Two undyed, plain weave fabrics served as the artifact: a lightweight, degummed, Bombyx mori silk habutae (Testfabrics #609) and a semi-dull nylon taffeta (Testfabrics #306A). Three undyed, open weave fabrics were used as support fabrics: nylon net (Dukeries N8000), polyester crepeline (Stabiltex, Tetex-TR), and silk crepeline. The fabrics were washed in a 0.3% (w/w) sodium lauryl sulphate detergent solution, rinsed with distilled water, and air dried at room temperature before being cut into swatches measuring 200 × 30 mm (warp × weft) and raveled to 20 mm in width. Fabric and yarn structure, fabric mass, and fabric tensile properties were determined using standard test procedures. The raveled swatches were randomly assigned to laminate groups before adhesive coating and heat-sealing. Six adhesives were used to produce the laminates (Table 1). Five — Acryloid (Paraloid) F10, BEVA 371, Lascaux 360HV and 498HV, Vinamul 3252, and adhesives equivalent to Clariant T1601 (Mowilith DMC2 and Appretan MB extra) — had been used by textile conservators and tested for conservation purposes (Berger 1972; Blackshaw and Ward 1982; Down et al. 1996; Horton-James et al. 1991; Howells et al. 1984; Verdu et al. 1984). Dur-O-Set E150, a neat dispersion, had been tested for its stability and suitability for conservation at the Canadian Conservation Institute (Down 1999).

Adhesives were prepared and applied using textile conservation techniques (Keyserlingk and Down 1999). Dispersion adhesives were diluted with distilled water to two levels of adhesive concentration: 1:10 and 1:5 (volume adhesive : volume solvent). The two Lascaux acrylic dispersions were combined in a 1:1 mass ratio prior to dilution. Resin solutions were produced by diluting 1 part resin by volume with 8 parts toluene for Acryloid F10 and 1 part toluene for BEVA 371. BEVA 371 solutions were heated in a water bath at 40ºC to ensure proper mixing.

Diluted adhesives were either brushed or sprayed onto the support fabric swatches. For brushing, swatches were clamped to a sheet of Teflon-coated glass cloth attached to a level glass plate in a fume hood. The adhesive was applied in a single brush stroke. BEVA 371 and Acryloid F10 solutions were also applied using a Preval aerosol sprayer from a distance of 1.1 m through a cardboard tube, one end of which was set into a fume hood. The support fabric swatch was clipped to the end of the tube in the fume hood. The adhesives were sprayed from the other end for 4 s. All coated swatches were allowed to air dry in the fume hood overnight at 19 ± 1ºC and 33 ± 4% RH. The mass of the adhesive coating (add-on) was determined for each specimen by measuring the mass of the support fabric swatches before and after coating. The degree to which the dried adhesive film coated the support fabric yarns and filled the interstices was also classified visually. Coated swatches were stored in the dark for 6 weeks before heat-sealing.

Table 1. Adhesive composition.

Adhesive	**Polymer**	**Major additives**
Resins		
Acryloid F10	PBMA	Stoddard solvent, other hydrocarbon and aromatic solvents
BEVA 371	EVA	Laropal K80, paraffin, phthalate ester of hydroabietyl alcohol, toluene, VM&P naptha
Dispersions		
Clariant T1601	VAC/maleate terpolymer	hydroxyethyl cellulose stabilized
Lascaux 360/498HV	PBA/PMMA	acrylic butylester thickener
Dur-O-Set E150	VAE	poly(vinyl alcohol) stabilized
Vinamul 3252	VAE	poly(vinyl alcohol) stabilized, sodium carboxy methyl cellulose

The coated support fabric swatches were heat-sealed to artifact fabric swatches in a modified Seal Commercial 210 M drymount press. A Ducor ERO-0204 temperature controller attached to the press by a thermocouple controlled the temperature within ± 1°C. The fully locked position of the press during heat-sealing ensured consistent pressure. Layered swatches were heat-sealed for 20 s at either 65°C (Acryloid, BEVA, Lascaux) or 95°C (Clariant, Dur-O-Set, Vinamul) as determined through pre-testing. Adhesion of the upper 40 mm and raveled edges of each specimen was prevented by inserting polyester film (12.7 µm Mylar) between the swatches. Laminated specimens were stored in the dark for 6 weeks before peel testing.

Determination of peel strength

Peel strength was determined using a T-peel test according to the procedures of the test method CAN/CGSB-4.2 No. 65-M91 (Canadian General Standards Board 1997). Tests were conducted on an Instron Universal Testing Instrument, Model 4202, using a 2.5 N load cell and 6-mm-wide spring-loaded fibre grips set at a gauge length of 25 mm. The non-adhered fabric ends were reinforced with self-adhesive paper tabs so that the grain of the edges extending beyond the grips remained aligned during peeling. The reinforced ends of the artifact strip and coated support fabric were placed in the upper and lower grips respectively (Figure 1). Each specimen was then peeled over 10 mm of its adhered length at a crosshead speed of 50 mm min^{-1} (International Organization for Standardization 1993). Tests were conducted in a controlled environment of 20 ± 2ºC and 65 ± 2% RH. Peel strength was calculated manually from the resulting graph for each specimen. The five highest and five lowest peak forces were recorded and these 10 values averaged. The peel strength per metre width was calculated as follows:

$$\text{peel strength (N m}^{-1}\text{)} = \text{average peak force (N) / width of specimen (m)}$$

The peel strength values of 10 specimens represented each treatment group.

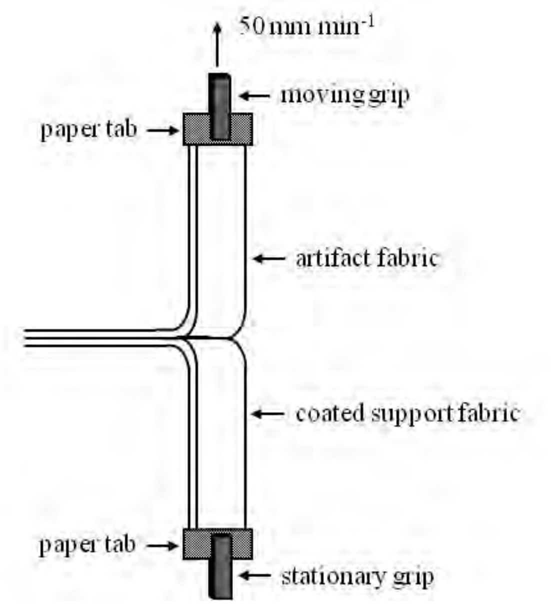


Figure 1. Configuration of laminated specimen for T-peel test.

The results of the peel tests were further characterized through visual observation and scanning electron microscopy (SEM). The relative amount of adhesive transfer to the artifact fabric during peeling was recorded. The artifact and coated support fabric surfaces of peeled laminates were examined using SEM in order to characterize the nature of the adhesive coatings and whether failure was adhesive, cohesive, or mixed. Small pieces of laminate were cut from the unpeeled ends of representative specimens. The pieces were adhered to stubs with carbon tape, support fabric side down. The artifact fabric was peeled back manually and adhered in place. The specimens were sputter-coated with gold prior to examination in a Jeol JSM 6301 FXV at 5 kV.

Data analysis

The significance of the effects of adhesive type (formulation plus application technique), artifact fabric, and support fabric was determined through three-way analysis of variance (ANOVA) and a multiple comparisons test coupled with Tukey's adjustment using SAS, release 8.2.

Results

Adhesive coating

The manner in which the adhesive solutions dried to coat the yarns and fill the interstices of the support fabrics varied by adhesive type and support fabric (Table 2). The 1:10 solutions of dispersion adhesives tended to coat or almost coat all yarns. Doubling the concentration resulted in approximately twice the adhesive add-on (Table 3), filling some interstices particularly when the support fabric was nylon net. Lascaux 360/498HV coatings seemed to be anomalous in that apparent filling of interstices was observed even with the more dilute solutions. SEM photographs of a representative coating showed that the adhesive film, which was poorly anchored to the support fabric yarns, filled many interstices but only partially (Figure 2). The solvent-based adhesives produced opposite results. The less viscous solution of Acryloid F10 partially coated yarns on one surface of the fabrics when brushed, but coated yarns on all sides using about twice as much adhesive (Table 3) when sprayed. The more concentrated BEVA 371 solution also coated the yarns when sprayed but with particles of adhesive. When brushed, BEVA 371 deposited slightly more adhesive (Table 3) and produced a continuous film over the fabrics.

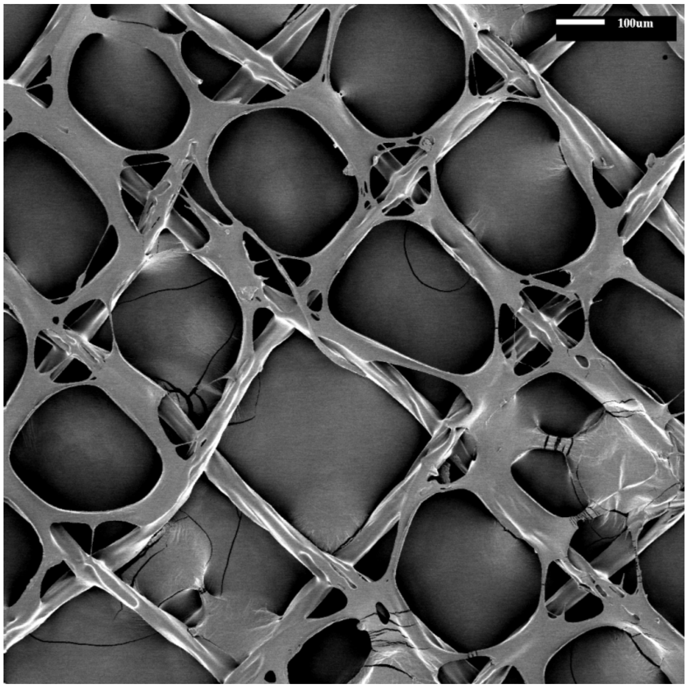


Figure 2. Coating of Lascaux 360/498 HV (1:1 by weight) brushed as a 1:5 (v/v) solution in distilled water onto silk crepeline.

Table 2. Classification of adhesive coatings by the degree to which the adhesive coats the support fabrics, nylon net (N), polyester crepeline (P), and silk crepeline (S).

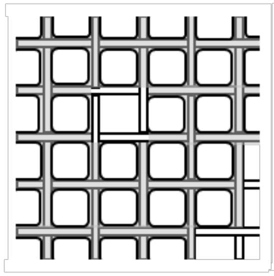
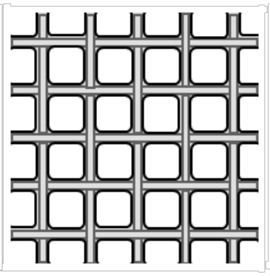
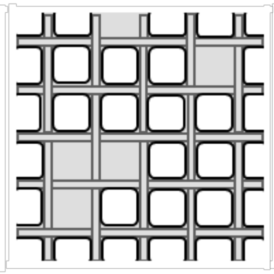
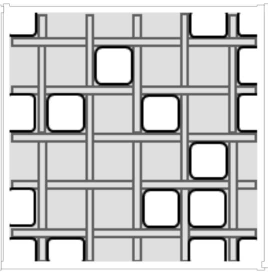
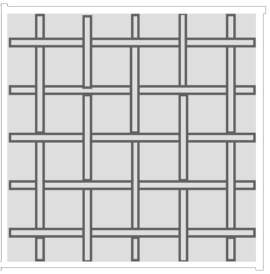
Coating description	*yarns almost coated*	*yarns coated*	*few interstices filled*	*many interstices filled*	*all interstices filled*
Adhesive					
Acryloid F10	1:8 brush/S,P,N	1:8 spray/N,P,S			
Clariant T1601	1:10/S	1:10/P/1:5/S	1:10/N/1:5/P	1:5/N	
Dur-O-Set E150	1:10/S	1:10/P	1:10/N 1:5/P,S	1:5/N	
Vinamul 3252		1:10/S,P	1:10/N 1:5/P,S 1:5/N		
Lascaux 360/498 HV			1:10/N,P 1:5/P	1:10/S 1:5/S,N	
BEVA 371		1:1 spray/N,P,S			1:1brush/N,P,S

Table 3. Mean peel strengths (with standard deviation) by adhesive, technique, artifact fabric, and support fabric.

Adhesive/ Support fabric	**Adhesive add-on (g)**	**Peel strength (Nm^{-1})**		**Adhesive add-on (g)**	**Peel strength (Nm^{-1})**	
		Nylon taffeta	**Silk habutae**		**Nylon taffeta**	**Silk habutae**
Acryloid F10	*1:8 (v/v) by brush*			*1:8 (v/v) by spray*		
Nylon net	0.0063 ± 0.0014	1.4 ± 0.2	3.0 ± 0.3	0.0113 ± 0.0015	1.0 ± 0.2	2.0 ± 0.3
Polyester crepeline	0.0082 ± 0.0016	1.5 ± 0.2	2.8 ± 0.5	0.0168 ± 0.0028	1.0 ± 0.2	1.8 ± 0.3
Silk crepeline	0.0087 ± 0.0020	1.4 ± 0.3	2.2 ± 0.5	0.0175 ± 0.0038	0.9 ± 0.3	1.7 ± 0.3
Clariant T1601	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
Nylon net	0.0087 ± 0.0012	3.9 ± 0.7	9.8 ± 1.9	0.0206 ± 0.0051	6.3 ± 1.2	18.7 ± 2.5
Polyester crepeline	0.0127 ± 0.0014	7.1 ± 1.3	18.2 ± 3.4	0.0251 ± 0.0032	12.9 ± 2.3	33.3 ± 3.2
Silk crepeline	0.0140 ± 0.0034	6.1 ± 1.8	13.8 ± 3.8	0.0263 ± 0.0038	10.5 ± 1.7	24.7 ± 2.5
Lascaux 360/498HV	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
Nylon net	0.0110 ± 0.0019	7.0 ± 2.1	11.6 ± 2.4	0.0240 ± 0.0072	22.0 ± 6.4	29.4 ± 5.9
Polyester crepeline	0.0126 ± 0.0017	6.0 ± 1.8	9.9 ± 2.4	0.0255 ± 0.0038	25.0 ± 5.2	31.1 ± 6.8
Silk crepeline	0.0142 ± 0.0031	7.4 ± 1.8	8.1 ± 1.6	0.0273 ± 0.0048	17.9 ± 4.1	22.7 ± 3.7
Dur-O-Set E150	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
Nylon net	0.0100 ± 0.0032	7.7 ± 2.3	16.4 ± 5.6	0.0241 ± 0.0046	11.7 ± 1.5	25.4 ± 3.7
Polyester crepeline	0.0151 ± 0.0031	14.2 ± 2.4	25.9 ± 6.5	0.0258 ± 0.0043	18.9 ± 3.2	36.8 ± 5.7
Silk crepeline	0.0156 ± 0.0025	11.8 ± 2.6	19.3 ± 4.3	0.0287 ± 0.0038	17.2 ± 2.9	30.2 ± 4.9
Vinamul 3252	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
Nylon net	0.0104 ± 0.0029	9.5 ± 2.8	13.5 ± 3.0	0.0205 ± 0.0038	20.0 ± 5.2	27.1 ± 6.8
Polyester crepeline	0.0134 ± 0.0018	14.2 ± 2.7	19.7 ± 3.5	0.0243 ± 0.0042	28.9 ± 3.4	39.2 ± 8.2
Silk crepeline	0.0161 ± 0.0021	12.2 ± 2.0	17.4 ± 3.2	0.0272 ± 0.0043	29.8 ± 4.1	36.0 ± 4.9
BEVA 371	*1:1 (v/v) by brush*			*1:1 (v/v) by spray*		
Nylon net	0.0502 ± 0.0105	34.8 ± 6.7	47.5 ± 15.3	0.0323 ± 0.0055	32.9 ± 6.2	42.0 ± 9.3
Polyester crepeline	0.0492 ± 0.0130	42.6 ± 6.7	50.7 ± 9.5	0.0466 ± 0.0060	53.2 ± 6.5	72.1 ± 9.5
Silk crepeline	0.0586 ± 0.0117	46.7 ± 13.0	56.7 ± 13.3	0.0460 ± 0.0085	49.5 ± 11.4	63.2 ± 13.2

Peel strength

The laminate types exhibited a wide range of peel strength values (Table 3). The ANOVA results revealed the overall significance of the effects of adhesive type (formulation plus application technique) and laminate fabrics on peel strength but also indicated significant interactions between these factors.

Effect of application technique

Adhesive concentration clearly affected peel strength. The peel strength of fabric laminates produced using a 1:5 (v/v) solution of an adhesive was always significantly higher than the corresponding laminates produced with a 1:10 (v/v) solution for all artifact/support fabric combinations. Twice as much adhesive by volume in the dispersion solution generated bonds that were approximately twice as strong (Table 3).

The effect of spray versus brush application depended on the type of adhesive. For Acryloid F10, brush application of a 1:8 (v/v) toluene solution gave significantly higher peel strengths than spray application for all artifact/support fabric combinations (Table 3). BEVA 371 tended to follow the same pattern only when the support fabric was nylon net. Spray application of a 1:1 (v/v) toluene solution of BEVA 371, in contrast, yielded higher peel strengths than brush application when the support was polyester or silk crepeline. Because of considerable variation in the results, the differences for BEVA 371 were only significant when the support fabric was polyester crepeline.

Effect of the artifact fabric

The artifact fabrics used to create the laminates also significantly affected peel strength. Nylon taffeta laminates consistently exhibited weaker adhesive bonds than the corresponding silk habutae laminates regardless of adhesive type or manner of application (Figure 3).

Effect of support fabric

Multiple comparison tests indicated the particular effects of the support fabrics on peel strength. Silk habutae and nylon taffeta laminates supported with nylon net were weaker than the corresponding laminates supported with silk or polyester crepeline when the adhesive was Clariant T1601, Dur-O-Set E150, Vinamul 3252, or sprayed BEVA 371 (Figure 4). The peel strengths of the silk and polyester crepeline laminates for these adhesives were not significantly different, even though polyester crepeline laminate bonds were usually stronger on average. Silk crepeline specimens adhered with a 1:5 (v/v) solution of Lascaux 360/498 HV had weaker peel strengths than the corresponding polyester crepeline specimens. The Lascaux specimens supported with nylon net had intermediate peel strengths and were not statistically different from those supported with either silk or polyester crepeline. The peel strength of laminates adhered with Acryloid F10, BEVA 371 applied by brush, and a 1:10 (v/v) solution of Lascaux to the three support fabrics could not be statistically distinguished when artifact fabric and application technique were held constant.

Effect of adhesive

Overall, Acryloid F10 laminates had the weakest bonds (1–3 N m^{-1}) and BEVA 371 the strongest (33–72 N m^{-1}) while dispersion adhesive bonds were of intermediate strength (4–39 N m^{-1}, Table 3). These distinctions were statistically significant for both silk and nylon artifact fabrics and for all three support fabrics regardless of application technique.

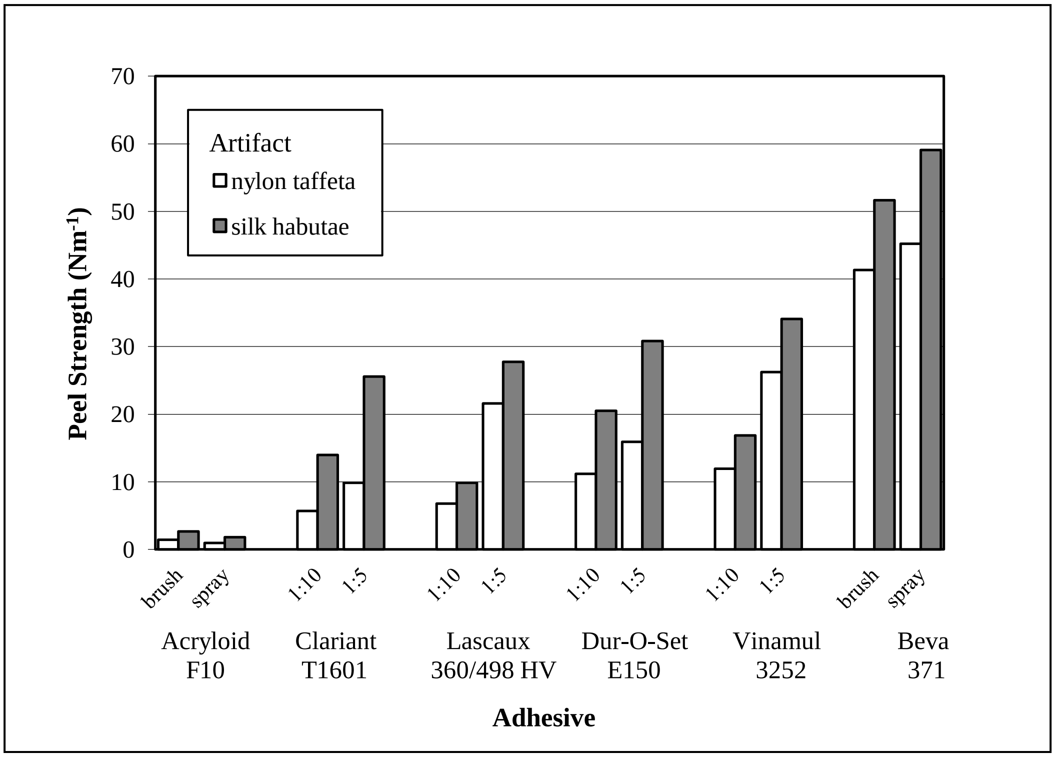


Figure 3. Peel strength (N m^{-1}) of nylon taffeta and silk habutae laminates adhered with Acryloid F10, BEVA 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252 averaged over three support fabrics.

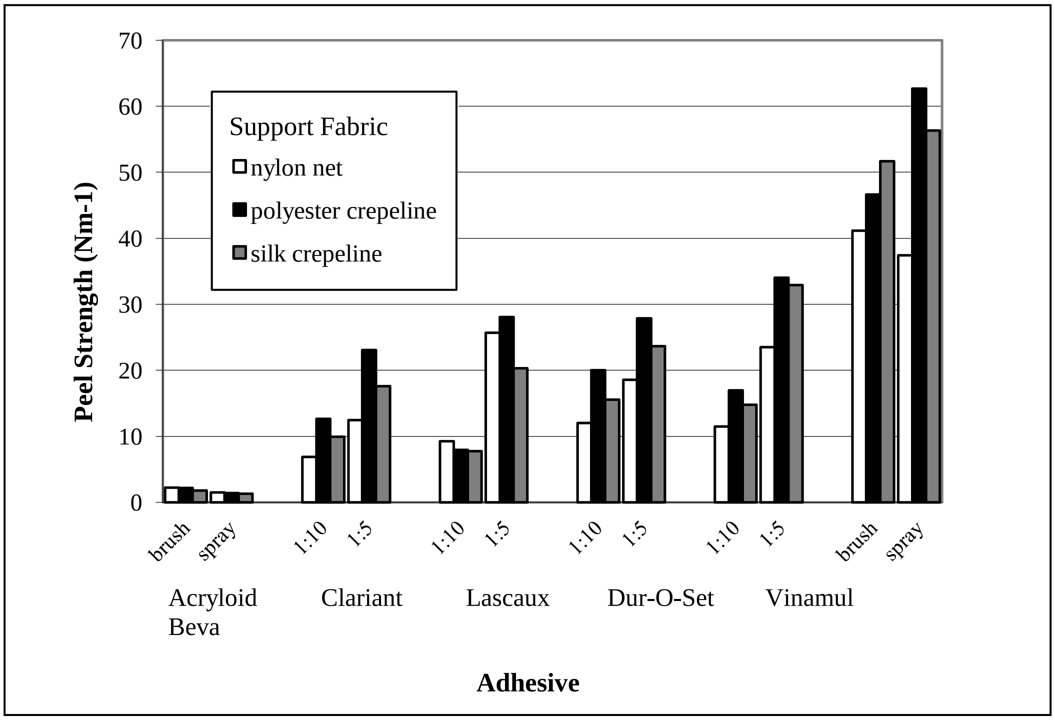


Figure 4. Peel strength (N m^{-1}) of laminates having nylon net, polyester crepeline, and silk crepeline supports adhered with Acryloid F10, BEVA 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252 averaged over the two artifact fabrics.

Relative bond strength of the dispersion adhesives depended on the particular artifact or support fabric and on whether the adhesive was applied as a 1:10 or 1:5 (v/v) solution. In general, however, Clariant T1601 produced bonds that were consistently weaker than those produced by Dur-O-Set E150 and Vinamul 3252. The range of bond strengths produced with Lascaux 360/498 HV was broader than that for the other dispersions. For 1:10 (v/v) solutions, the Lascaux bonds were usually weaker or equivalent to Clariant bonds, while for 1:5 (v/v) solutions, they were stronger than or equivalent to Dur-O-Set bonds.

Bond failure

The peeling behaviour of the adhesives was classified according to whether the adhesive transferred to the artifact fabric during peeling or remained on the support fabric (Table 4). All adhesives exhibited some transfer except the one that formed the weakest bonds, Acryloid F10. Transfer was observed on Clariant T1601 and Dur-O-Set E150 specimens only when the support fabric was nylon net. Lascaux 360/498 HV and Vinamul 3252 showed transfer when the artifact fabric was nylon taffeta or when the support was nylon net. BEVA 371 exhibited substantial transfer when the coating was sprayed and slight transfer when it was brushed onto nylon net or adhered to nylon taffeta. Observation of the peel front during peel testing indicated differences in how this transfer occurred (Figure 5). Coatings of three adhesives — BEVA 371, Lascaux 360/498 HV, and Vinamul 3252 — were stretched into fibrils when subjected to peel force. Transfer occurred with Clariant T1601 and Dur-O-Set E150 when the coating broke away from fabric interstices.

Table 4. Amount of adhesive transferred to the artifact fabric during peeling according to the type of fabrics and the application technique used to make the laminate. Observations were classified as none (N/green), slight (S/yellow), or lots (L/white); colour indicates the most prevalent classification when more than one occurred.

	Artifact and support fabrics											
	Nylon taffeta						Silk habutae					
	Nylon		Polyester		Silk		Nylon		Polyester		Silk	
Adhesive	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5
Acryloid F10	N	N	N	N	N	N	N	N	N	N	N	N
BEVA 371	S	L	N/S	L	N/S	L	S	L	N	L	N	L
Clariant T 1601	S/N	S	N	N	N	N	N/S	S/L	N	N	N	N
Dur-O-Set E150	S/N	S	N	N	N	N	N/S	S	N	N	N	N
Lascaux 360/498 HV (1:1)	S	L	N	N	N	N/S	N/S	L	N	N	N	N
Vinamul 3252	S	L	N/S	N/S	N	N	S/N/L	L	N	N	N	N

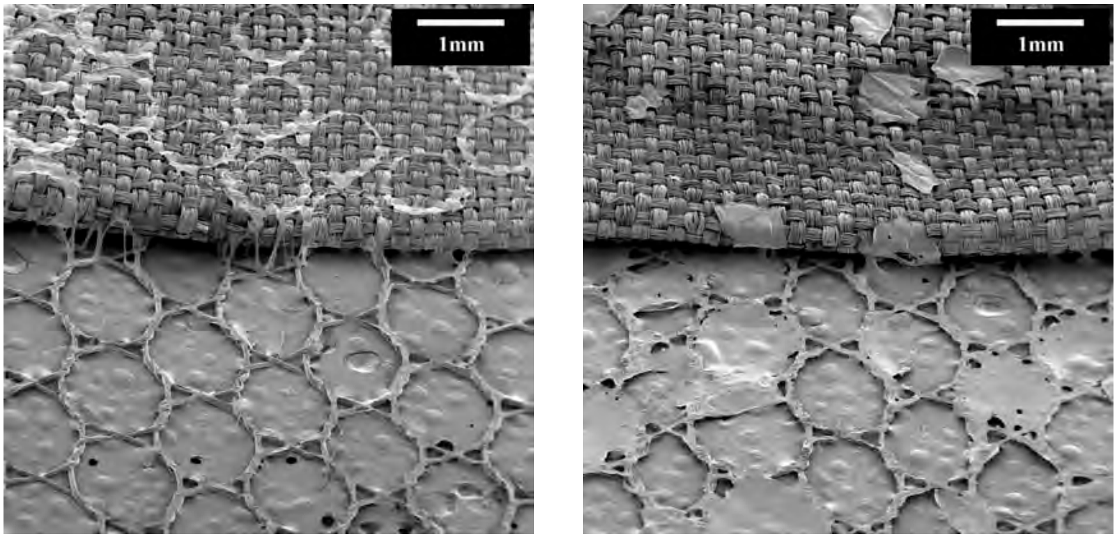


Figure 5. Peel behaviour of Lascaux 360/498 HV (left) and Clariant T1601 (right) brushed as a 1:5 (v/v) solution in distilled water onto nylon net and adhered to silk habutae. Lascaux 360/498 HV exhibits adhesive stretching and transfer to artifact fabric while Clariant T1601 shows adhesive transfer from the interstices of the coated net. (Note: carbon tape is visible through most of the nylon net interstices.)

Discussion

Adhesive effects

Adhesive distribution

The results of this study indicate that conservators can significantly influence the peel strength of textile/adhesive/support fabric laminates through their choice of adhesive, support, and application technique. Techniques that deposit more adhesive, such as doubling the concentration of a dispersion adhesive solution, provide more adhesive for bonding and thus higher peel strength. The adhesive that gave the strongest bonds, BEVA 371, also had the highest adhesive add-on, while Acryloid F10, which gave the weakest bonds, had the lowest adhesive add-on (Table 3). The other adhesives (dispersion solutions) gave intermediate adhesive add-on and intermediate bond strengths. A plot of peel strength versus adhesive add-on thus exhibits good overall linear correlation ($R^2 = 0.67$, Figure 6)

But adhesive add-on cannot account for all the variation in peel strength. Figure 6 also shows that for a particular adhesive/application technique combination, more adhesive does not always increase bond strength. Where the adhesive is deposited also plays a role: only adhesive that contributes to superficial bonding between fabrics adds to peel strength. Brushed Acryloid F10 formed a flat coating on one surface of support fabric yarns that provided more surface area for bonding with less adhesive add-on than sprayed coatings that conformed to the shape of the yarns (Figure 7a, b). In contrast, the sprayed coatings of BEVA 371 produced bonds exhibiting peel strengths as high as brushed coatings because the layer of fine adhesive particles deposited on one surface of the support fabric was almost all available for bonding (Figure 7c). Although brushed BEVA 371 provided the greatest surface area of adhesive available for bonding in a continuous film coating, greater add-on may have increased the thickness of the coating without contributing much to the peel strength of a surface bond. Not all interstitial adhesive contributed to peel strength: traces of artifact embedding were most frequently observed next to the support fabric yarns.

Support fabric structure influenced adhesive surface area available for bonding. The thread count of nylon net (9–10 yarns/cm) is one-half to one-third that of polyester (23 yarns/cm) and silk crepeline (20–30 yarns/cm) respectively, while the diameter of its yarns is similar (about 50–60 µm). Adhesive add-on on nylon net for formulations that coated only one surface of the yarns (10% Clariant T1601 and Dur-O-Set E150) was about 30–40% lower than that on silk or polyester crepeline. Similarly, the corresponding peel strength values for nylon net laminates were about 35–45% lower than of those for silk and polyester crepeline laminates. This distinction diminished at higher adhesive concentrations as the adhesive was more likely to fill the interstices of nylon net than those of polyester or silk crepeline. When the adhesive was applied in a manner that produced a continuous film, as with a brushed coating of BEVA 371, the adhesive surface area and add-on for the three support fabrics no longer differed significantly; neither did the peel strength of the corresponding laminates for a particular artifact fabric.

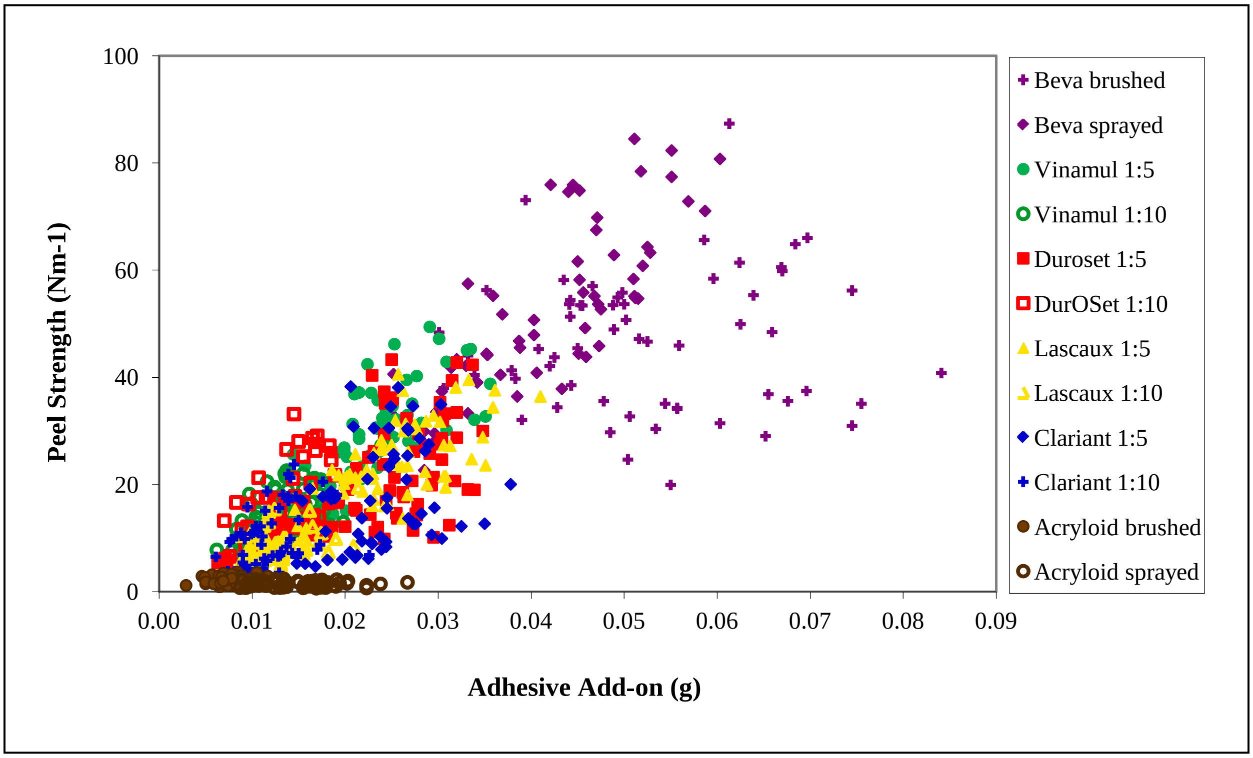


Figure 6. The relationship between adhesive coating mass (add-on), adhesive type, and peel strength.

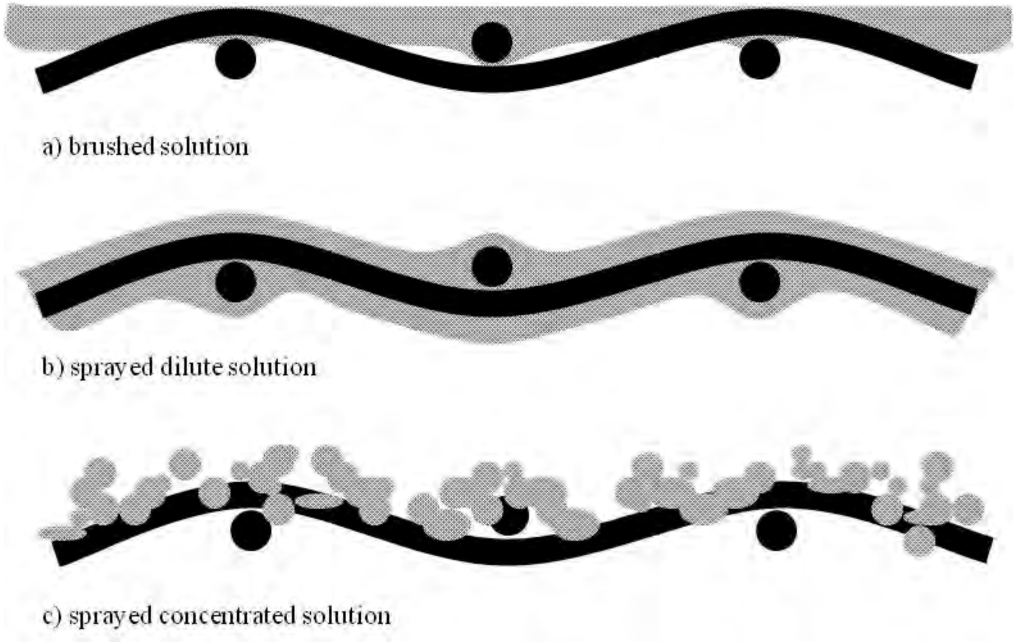


Figure 7. Adhesive coating types produced by resin adhesives applied by (a) brush or sprayed as a (b) dilute or (c) concentrated solution.

Bond failure mechanisms

Whether or not adhesive is transferred to the artifact fabric during peeling appears to be related to mechanical properties of the adhesives and to how well adhesive coatings attach to the support fabrics. Failure is adhesive in nature (i.e. at the adhesive–artifact fabric interface) when the adhesive is relatively stiff under the test conditions or when the coating is well attached to the support fabric. When, by contrast, the adhesive is relatively flexible and extensible or poorly attached, failure is cohesive within the adhesive layer resulting in transfer of adhesive residue to the artifact fabric on peeling. The stiffest adhesives as indicated by high modulus (Down et al. 1996; Down 1999), Acryloid F10 and Clariant T1601, exhibited little adhesive transfer during peeling. More flexible adhesives, such as BEVA 371 and Lascaux 360/498 HV, exhibited substantial transfer except when well anchored to the support fabric as was the case when these adhesives were applied by brush to silk or polyester crepeline. Adhesive coatings on nylon net, on the other hand, exhibited greater degrees of adhesive transfer. Both the large size of the interstices and its construction from monofilament yarns, which provide few points for mechanical interlocking of the coating, may predispose nylon net to adhesive transfer during peeling.

Using an adhesive that stretches easily when subjected to stress is both advantageous and problematic for adhesive support treatments for textile artifacts. The ability of the adhesive to stretch into filaments is often related to high peel strengths, since force is dissipated in deforming the adhesive and is not concentrated at the interface where it would break the adhesive–fibre bond. Higher peel strength means that the treated artifact can be handled and manipulated to a greater degree without fear of bond failure. Thus, adhesives such as BEVA 371 and Vinamul 3252 are probably most appropriate for three-dimensional textile artifacts or flat artifacts that will be rolled for storage. In contrast, accidental delamination of two Acryloid F10 specimens before peel testing during this study confirmed that artifacts adhered with this adhesive in the manner applied would have to be handled very carefully to prevent bond failure.

If an adhered support needs to be removed, however, an extensible adhesive that tends to transfer to the artifact makes the task more difficult. Conservators often use heat or solvent vapour to reduce the bond strength if using a peeling technique to remove the support (Boersma 1998; Cruickshank et al. 1998; Landi 1992). Both heat and solvent vapour increase the extensibility of the adhesive, making adhesive transfer more likely. Thus Pretzel (1997a; 1997b) observed adhesive transfer for Lascaux 360/498 HV during a hot peel test but not during a peel test under ambient conditions. Cohesive failure within the adhesive is also more likely at slow peel rates (Derail et al. 1998), which textile conservators use instinctively in order to protect the relatively weak fibres of the artifact. If reversal without adhesive transfer is important for a particular artifact, a relatively stiff adhesive, such as Acryloid F10 or Clariant T1601, and a rigid mount to reduce the risk of unwanted delamination may be the best alternative.

Fabric effects

Artifact fabrics

That silk habutae laminates had higher peel strengths than the corresponding nylon taffeta laminates can be attributed to chemical properties and fabric structure. Silk is a more polar fibre, containing more amide linkages, and thus >C═O and >N—H polar bonding sites, than nylon where aliphatic chains of $—CH_2$ groups separate the amide groups. Additional polar groups on amino acid side chains of the protein fibre, such as the hydroxyls of serine ($—CH_2OH$), add to silk's polarity. Polar groups provide sites for potential acid–base interactions and hydrogen bonding with polar groups on adhesive polymer molecules that contribute to bond strength. In addition, the triangular cross-sectional shape of silk fibres, their slightly rough surfaces, and their relatively loose packing in the habutae yarns may have optimized the surface area available for bonding when compared to the relatively smooth, circular, densely packed nylon fibres in the taffeta yarns (Figure 8). Given this difference in peel strength, a "stronger" adhesive may be needed for a nylon artifact to achieve a bond strength equivalent to that found suitable for silk fabrics of the same weave. If, for example, silk crepeline coated with Clariant T1601 produced bonds of adequate strength for silk habutae artifacts (14–25 N m^{-1} depending on concentration, see Table 3), a conservator would need to use a similar solution of Vinamul 3252 on silk crepeline to produced the same bond strength with nylon taffeta artifacts (12–30 N m^{-1}). Clariant T1601 bonds to nylon would be much weaker (6–11 N m^{-1}). Although few adhesive support treatments of nylon artifacts have been described in the literature, the tendency for nylon to embrittle when exposed to light in a manner similar to silk suggests that adhered supports might be considered for such textiles in the future.

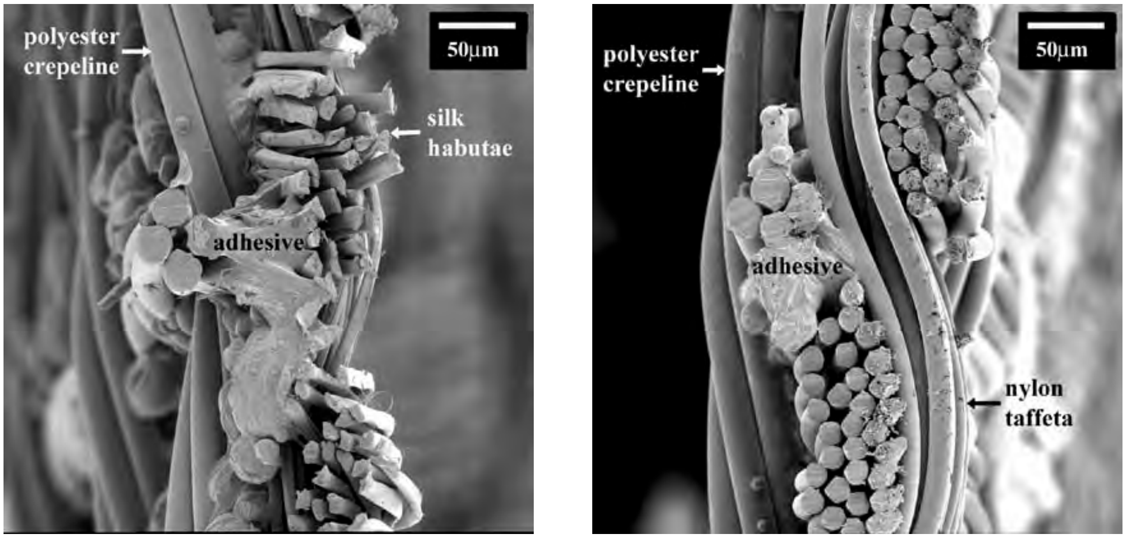


Figure 8. Silk habutae (left) and nylon taffeta (right) adhered to polyester crepeline with a sprayed coating of BEVA 371 in toluene (1:1, v/v) showing how the difference in fibre cross-section and yarn structure may optimize bonding to silk habutae.

Support fabrics

The effect of support fabric on peel strength is less consistent than that of artifact fabric. That the bonds of laminates supported on nylon net are weaker than those on silk or polyester crepeline for a number of adhesives is partly due to the amount of adhesive add-on, as already described, but may also be due to the relative flexibility of nylon net in comparison to polyester or silk crepeline. With an initial modulus (2.4 N mm^{-1}) less than a third of that of polyester crepeline (8.1 N mm^{-1}) and silk crepeline (8.5 N mm^{-1}), little force is expended in bending nylon net into the peel configuration. In general, this study suggests that polyester and silk crepeline do not produce bonds of significantly different peel strength. Lower bond strengths can be expected from nylon net, however, when the adhesive coating does not form a continuous film over the fabric interstices.

Conclusions

This study has shown that materials (adhesives, artifact fabrics, and support fabrics) and application techniques used in adhesive support treatments for textile artifacts significantly affect the peel strength of the laminated textile. Doubling the concentration of a dispersion adhesive solution doubled the peel strength of the laminates. Spraying rather than brushing produced significantly weaker peel strength when the adhesive was Acryloid F10 but did not significantly affect the results of BEVA 371. Adhesive bonds to silk habutae were stronger than those to nylon taffeta. Laminates supported with nylon net had weaker bonds than those on polyester and silk crepeline for several adhesive formulations but not when the adhesive formed a continuous film. The type of adhesive used clearly influenced peel strength as well, although variations in application technique made a single ranking by peel strength impossible. Many of the differences in peel strength can be attributed to differences in the surface area of adhesive available for bonding, although the artifact fabric differences are probably due to differences in fibre chemistry and yarn structure. Although this study compared a limited selection of adhesive application variables, its results contribute to a better understanding of the factors that affect laminate peel strength, which can help conservators make good treatment decisions with regards to materials used in the adhesive support of textile artifacts.

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Acryloid F-10 (Rohm and Haas)
International Gilders' Supplies
12-1541 Star Top Road
Ottawa ON K1B 5P2 Canada
Tel.: 613-744-4282
Fax: 613-744-0949
Website: www.gilding-supplies.com

BEVA 371
Conservator's Products Company (Canada) Ltd.
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Tel. 416-539-8069
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Clariant T1601
Clariant (Canada) Inc.
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Tel.: 514-334-1117
Fax: 514-334-6232

Dur-O-Set E150
Nacan Products Ltd.
60 West Drive
Brampton ON L6T 4W7 Canada
Tel.: 905-454-4466
Fax: 905-454-5207
Website: http://www.nacan.com

Lascaux 360HV, Lascaux 498HV
Lascaux Restauro
Alois K. Diethelm AG Lascaux Farbenfabrik
Zürichstrasse 42
CH-8306 Brüttisellen, Switzerland
Tel.: 41 1 807 41 41
Fax: 41 1 807 41 40
Website: http://www.lascaux.ch

Vinamul 3252
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Eastford Road
Warrington, Cheshire WA4 6HG, United Kingdom
Tel.: 44 0 1925 236400
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Silk habutae, nylon taffeta
Testfabrics
PO Box 26
West Pittson PA 18643 USA
Tel.: 570-603-0432
Fax: 570-603-0433
Website: http://www.testfabrics.com

Silk crepeline, polyester Tetex-TR
Talas
568 Broadway
New York NY 10012 USA
Tel.: 212-219-0770
Fax: 212-219-0735
Website: http://www.talasonline.com

Nylon net (N8000)
Dukeries Textiles & Fancy Goods Ltd.
Spenica House
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