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Predicting Failure in Hinges: Measurement of a Lap/Shear Bond between Japanese Tissue, Wheat Starch Paste, and Oil-Saturated Newsprint

ABSTRACT

Traditional wheat starch paste is a reliable and reversible adhesive used for archival hinging of works of art on paper. Yet, this time-tested, water-based adhesive does not always bond well to oil-saturated paper, as do several nonaqueous synthetic adhesives. However, due to problems with reversibility, aging characteristics, and the increased awareness of occupational risks associated with organic solvents, conservators do not generally recommend synthetic adhesives for long-term use on paper supports. In response to this problem, an experiment, modified from TAPPI Tensile Test T 813 om-91, was designed to measure the strength of wheat starch paste bonds when used to attach Japanese tissue hinges to aged, oil-saturated, newsprint. Commercial iron-oxide oil paints were applied by brush in a painterly, variegated pattern to sheets of wood pulp paper using two different dilutions: straight from the tube, and thinned with a commercial oil painting medium. The uneven paint coverage allowed comparison of the paste bond to oil-saturated paper relative to that of plain, unpainted, paper. Twenty-five 16" X 12" samples were light-aged naturally for eighteen months, and dark-aged for almost thirty-three months. Japanese tissue hinges were then attached to samples using cooked, strained, and thinned wheat starch paste. To secure the attachment, pressure was initially applied with a bone folder. Hinged samples were then placed under weights, using non- woven polyester webbing as interleaving, and desiccated blotters to absorb moisture. Lap/shear tensile tests were conducted at the Testing Facility of International Paper Company, Tuxedo Park, New York, using an Instron Model 1122 with a 5500R Series system interface, and Series IX software. Results indicate that while wheat starch paste remains a preferred adhesive for most paper supports, it is inadequate when used on oil-saturated paper.

1. INTRODUCTION

As a medium, oil paint has been employed on paper throughout the ages by artists ranging from Tintoretto, Jordaens, and Rubens, to deKooning, Kline, and Frankenthaler (Kosek and Green 1992), (Cove 1992). Realized as sketches, studies, or finished works, oil paintings on paper are found on both primed and unprimed paper supports.

When displaying these works, presentation formats may vary according to artistic intent, custom, and curatorial preferences. Works on paper have often been exhibited as traditional canvas easel paintings, by being mounted directly to paper, board, or canvas, and then wrapped around stretchers, or strip-lined and secured to the reverse of a solid support. Alternatively, such works may hang, suspended only from their top edges by strips of tissue, which are in turn, attached to a secondary support such as four-ply rag board. Typically, two or more long-fibered Japanese tissue "hinges" will be used to suspend the work of art on paper within a window mat. In this hinging process, the Japanese tissue is secured to the reverse of the painting with cooked, strained, and thinned wheat starch paste (fig. 1a-b and fig. 2).

Starch pastes have a long and successful tradition as adhesives in Eastern and Western art conservation and mounting (Winter 1984). Owing to their steric compatibility with cellulosics, and their relative ease of reversibility, starch pastes remain the preferred adhesive in most paper conservation procedures (Swanson 1972). Yet, empirical results show that this water-based carbohydrate adhesive does not consistently bond well to oil-saturated paper (Keynan and Weingarten 1991).

In order to hinge or line oil-saturated paper, conservators utilize a number of natural and synthetic adhesive alternatives, in combination or alone. For these hard-to-adhere joins, conservators have suggested mixtures of starch paste and gelatin (Fishman 1993); or mixtures of starch paste and poly(vinyl acetate) emulsions (Zukor

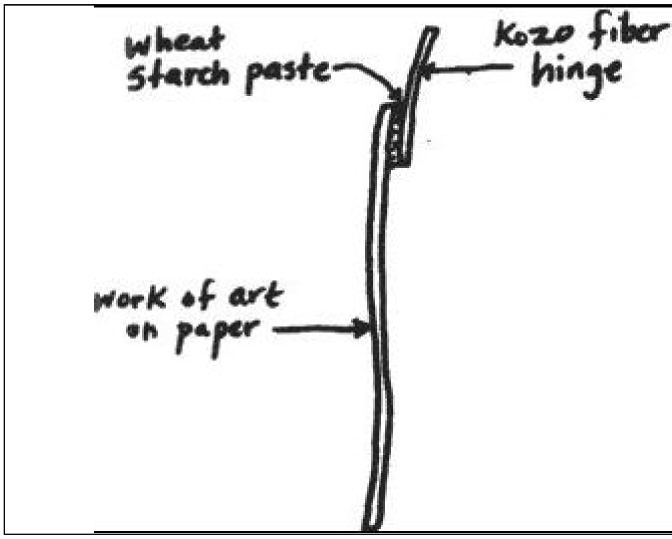

Fig. 1a. Side view of hinged work on paper

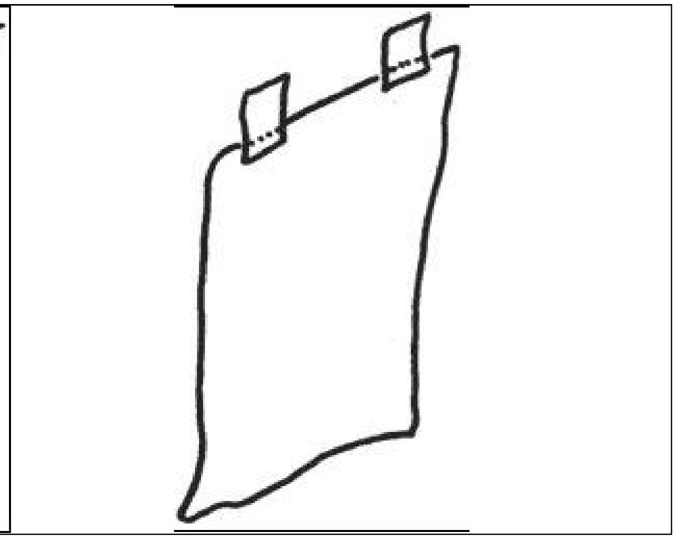

Fig. 1b. Verso of work of art with two hinges attached

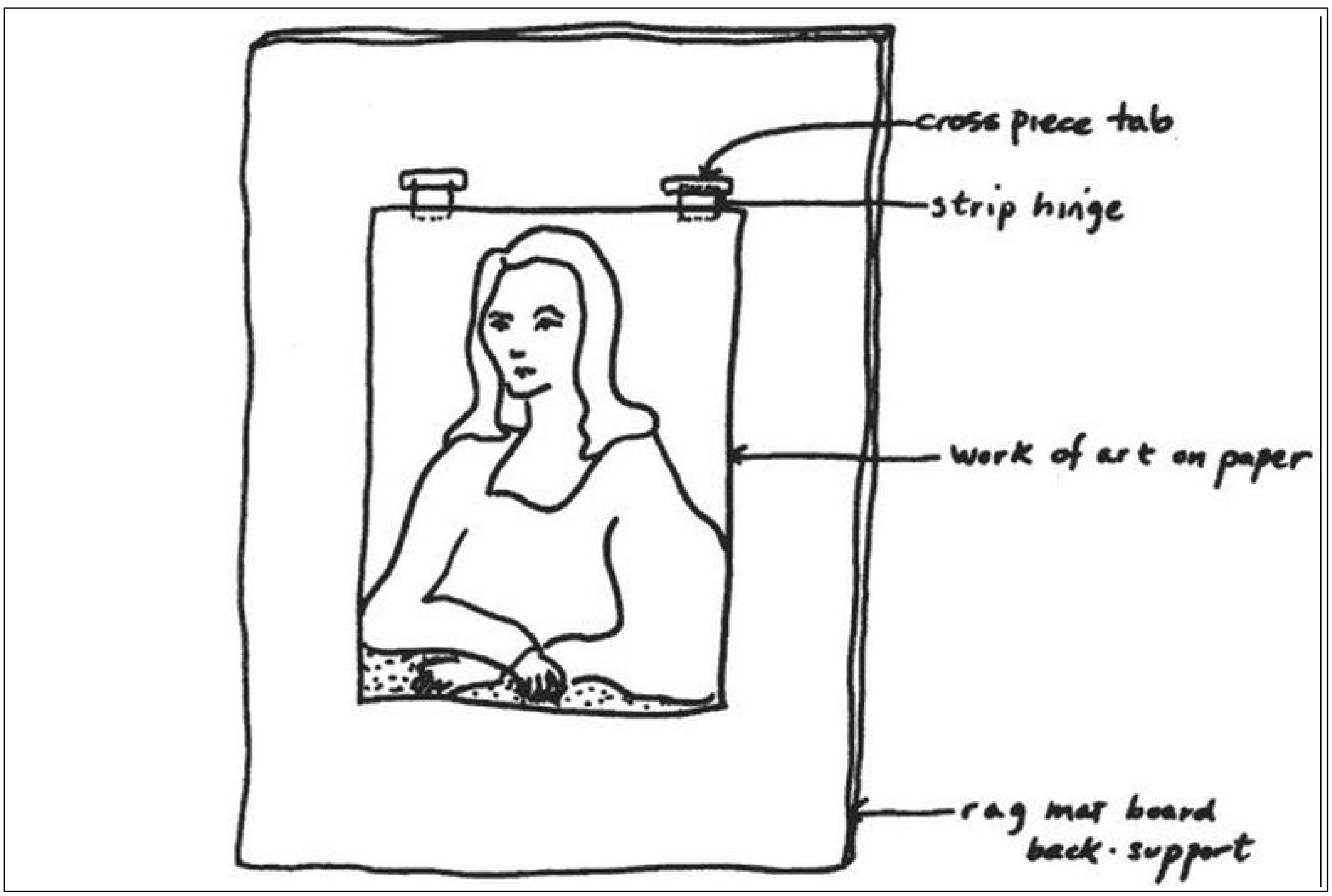

Fig. 2. Work of art on paper hinged with Japanese tissue and wheat starch paste, attached to rag mat board backer

1998). Heat- and solvent-activated synthetic adhesives such as Beva 371 (Perry and Townshend 1992) and Lascaux 498-20X (Maheux 1992) have also been advocated. In addition, the use of desiccated blotters is recommended to absorb excess moisture at the bonding site (Volent 1994). Conservators advocate using non-toxic, reversible adhesives for the health and safety interests of both the conservator and the works of art.

> One-of-a-kind or specially made paper/synthetic adhesive hinge systems may be indicated for temporary use on supports to which wheat starch paste will not adhere, or where, because of the nature of the support, moisture cannot be used for hinge application or later hinge removal (severe cockling) or for display of transparent objects. Caution: Synthetic adhesives are not recommended for permanent hinging and should only be used if they can be safely removed from the paper, i.e., solvents used for removal are safe to apply to the object. (Book and Paper Group/AIC 1988).

A preliminary literature search indicates that no adhesive is specifically recommended for hinging oil paintings on unprimed, i.e., oil saturated, paper supports.

2. EXPERIMENTAL

This experiment was designed to determine whether wheat starch paste, prepared according to standard practice, will bond and hold a Japanese tissue hinge to aged, unprimed, and oil-infused, newsprint paper. The objective of these tests is to recommend, or rule out, the reliability of wheat starch paste for use on oil-saturated paper supports, and to indicate other techniques and adhesives for future testing.

TAPPI Tensile Test T 813 om-91, tensile test for the manufacturer's joint of fiberboard shipping containers, was modified to test the efficacy of lap/shear joints in the archival hinge.

The arrangement of a "T-hinge" attached to a paper support with paste closely resembles the configuration of a lap/shear joint (Bikales 1971). (See fig. 3). [The "V-hinge" is another type of hinging configuration. It is subject to peel forces, and was not tested in this study.] The performance of conservation-grade adhesives has been studied in both lap/shear and peel tests as published by paintings conservators (Berger 1972), (Hedley 1984), and (Katz 1985)

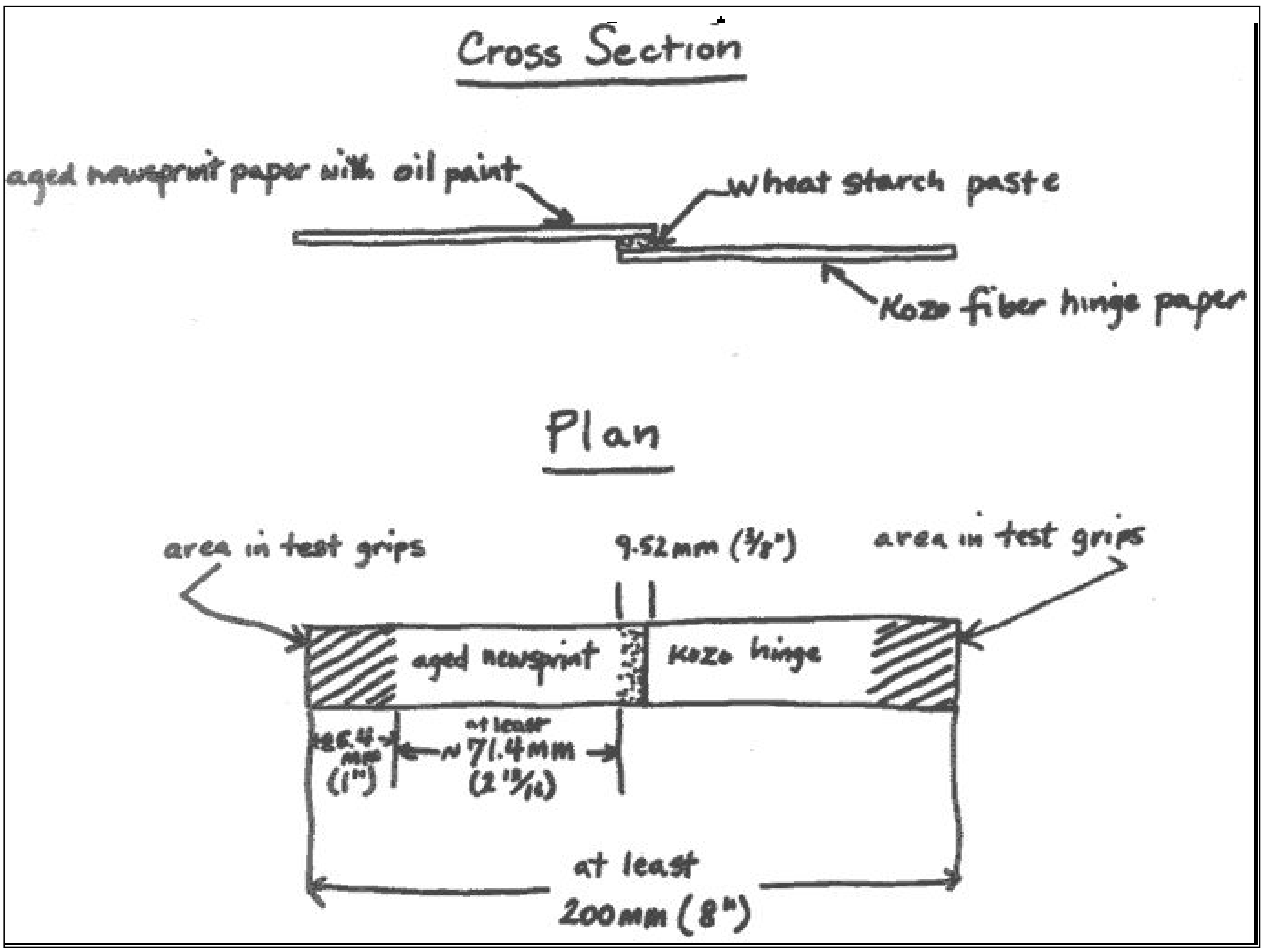

Fig. 3. Dimensions of test specimen

2.1 SAMPLE PREPARATION AND MATERIALS: PAPER AND OIL PAINT

Focusing the study on modern and contemporary works of art on paper, the test samples were prepared using commercially-manufactured artist materials. Sheets from a pad of 16" X 12" Morilla™ newsprint paper by Canson were designated as the support paper; Utrecht oil paint, prepared with linseed oil and packaged in tubes, was chosen as the test medium. The paints included two different iron-oxide pigment types, Yellow Ochre and English Red Light. They were applied by brush in two dilutions - in one group, paint was delivered straight from the tube, and in the other group, paint was first thinned with Winsor Newton brand oil painting medium, a mixture of stand oil and petroleum distillate.

Yellow ochre is a natural earth pigment with the chemical composition, $Fe_2O_3{\cdot}H_2O$, and may contain impurities such as gypsum and magnesium carbonate (Gettens and Stout 1966). With a medium oil index of approximately seventy-six pounds of oil per one-hundred pounds of pigment, it forms an excellent, strong paint film, and has a slow-to-average drying time. English Red Light is a descriptive name for maroon-colored anhydrous iron oxide, Fe_2O_3. It is a naturally-occurring earth pigment, and can be prepared chemically by heating ferrous sulfate with chalk; it usually contains gypsum. The label on Utrecht English Red Light describes the pigment as artificially-prepared. With a low to moderate oil index of about sixty-three pounds of oil per one-hundred pounds of pigment, English Red Light forms a good to fair (sometimes brittle) paint film, and has an average drying time (Mayer 1970), (Gottsegen 1993).

Working on a surface of prepared palette paper, the tube paints were thinned with Winsor Newton painting medium using a palette knife. During this process, it was observed that English Red Light wetted more easily, and became a less-viscous, more easily-manipulated paint mixture compared to the Yellow Ochre tube paint when prepared in a similar manner. Thinned English Red Light paint resembled an ink, in both consistency and flow properties, in contrast to the Yellow Ochre paint, which was found to be pasty, stringy, and more difficult both to dilute and to apply by brush. The greater 'wettability' of English Red Light, a synthetically-prepared pigment, seems to be due to its minute particle size.

For each paint type and dilution, a sheet of 16" X 12" newsprint was divided into four 8" X 6" quadrants, and lightly ruled with soft graphite pencil. Each sheet was oriented with the grain in the vertical direction, and painted. To replicate a painterly application, media was applied with a 2" wide flat bristle brush in a variegated fashion, i.e., in some cases the media reached the edges of the paper, and in some cases, the media did not. There was a range of paint loading and saturation.

2.2 NATURAL LIGHT AGING

Painted samples were stapled onto the walls of the studio of Rustin Levenson Art Conservation Associates, New York, New York in order to be light-aged (fig. 4). Facing south, the room receives ample sunlight throughout the day, and is exposed to a range of relative humidity and temperature levels. The samples were naturally light-aged from October 15, 1993 to April 11, 1995 for a total of eighteen months, four days. The samples were then removed, placed in flat storage with glassine interleaving, and dark aged from April 5, 1995 to December 26, 1997 — thirty-two months and twenty-one days.

Fig. 4. Four panels of painted samples at the studio of Rustin Levenson Art Conservation Associates, New York, New York, before light-aging

2.3 HINGE AND PASTE PREPARATION

In December, 1997, the 16"(H) X 12"(W) sheets were each cut into four 8"(H) X 6" (W) pieces using a Fletcher brand table mat cutter # 2100. Based on weight, strength, and handling properties, light-weight Sekishu Hanshi-mare tissue manufactured by Hiromi was selected as the hinge paper for this study. After aligning chain lines to correspond with the grain direction of the sample support paper, 2 3/4" (H) X 6" (W) strips of the Japanese tissue were water-torn. These dimensions allowed for a hinge/paste/newsprint lap-join with a 3/8" overlap, running the width of each trimmed sample. [Recommended paste coverage varies in height from one-quarter to one- half inch (Book and Paper Group/AIC 1988)].

A mixture of Zin Sho fu wheat starch and distilled water was prepared in a ratio of 1:4.5 starch to water by volume, first through hydrating, and then by cooking using a Tefal® Cook & Stir™ electric gravy maker. The cooking time was approximately forty-five minutes. During the cook, the temperature control was increased gradually to a setting midway between "4" and "5". After monitoring three distinct stages of the cook: 1) transformation from opaque to translucent mixture, 2) bursting of starch grains, and 3) change in viscosity from thicker to less thick gel, the heat setting was gradually lowered to zero. The cooked paste was then transferred to a sterilized glass container, and cooled in a water bath (Clapp 1987). After straining through a fine mesh plastic sieve, the paste was thinned with distilled water to a moderate-thin, heavy cream consistency (Phibbs 1994). Paste was made fresh on the day of hinging.

2.4 HINGING

Hinging took place in winter, 1998, in a heated room with an atmosphere approximating the preconditioning environment outlined in TAPPI T 402 om-88, standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products. Using humidity indicator strips, the relative humidity was measured at nearly forty per cent, just above the recommended relative humidity levels of 10-35%. The temperature measured 24.4 degrees C, within the specified range of 22-40 degrees C (72-104 degrees F).

Using a Mylar® template under the water-torn edge of the Sekishu Hanshi-mare hinging tissue, paste was applied by brush to the top three-eighths of an inch of the hinge paper. After air-drying for a few seconds, the pasted tissue was positioned on the top edge, verso, of the painted sample. Pressure was applied with a bone folder to help secure the bond. Polyester webbing was then positioned as a non-stick interleaf, followed by placement of desiccated blotter squares, used to wick off excess water. During the first hour, blotter squares were changed five times; in the five subsequent hours, blotter squares were changed one per hour; the hinges remained under weights overnight.

Hinges were applied four days prior to tensile testing. Batches were numbered and separated into two groups — one for current testing and one for future testing — by a coin toss. The samples were placed into an air-tight plastic bag separated by one-ply rag board.

3. TESTING

The experiment was conducted at the Testing Facility of International Paper Company, Tuxedo Park, New York, on January 6, 1998. Testing was performed under the direction of paper scientist, Dennis Crawshaw, and with the help of tensile test technician, John Conklin.

3.1 CONDITIONING ENVIRONMENT

The experiment was undertaken in the test environment of 50% and 73% F, within the range specified in TAPPI T 402 om-88, standard conditioning and testing atmospheres [relative humidity of 50% +/- 2%, and a temperature of 23.0 +/- 1.0 degrees C (73.4 +/- 1.8 degrees F)].

3.2 SAMPLE TRIMMING

Prior to tensile testing, each hinged sample was trimmed uniformly using a Thwing Albert 1" precision cutter model JDC 1-12, resulting in five one-inch-wide (25.0 +/- 0.5 mm) replicants per each 8" X 6" sample. Within each group type (I-IV), samples were labeled at the top of the hinge, from left to right, with letters "a" through "e" using a soft graphite pencil. The trimmed specimens were then conditioned to ambient levels of temperature and humidity for three hours.

3.3 TEST GROUPS

The test groups are depicted in Table 1 and as follows:

I YELLOW OCHRE STRAIGHT
II YELLOW OCHRE THINNED
III ENGLISH RED LIGHT - STRAIGHT
IV ENGLISH RED LIGHT — THINNED

As suggested by conservation literature, a pre-test trial was conducted (Bradley 1984). This initial trial batch of twenty specimens — five of each variant — was run to test the effects of different grips (both the one-inch flathead and the half-moon shaped grippers), at varying distances from the lap-joint (1/8" and 1"), and at different cross-head speeds (0.25 in/minute and 0.5 in/minute).

3.4 PROCEDURE

The test group of forty specimens — ten specimens of four variants each — were then tested. Lap/shear tensile tests were carried out on an Instron Tensile Tester, Model 1122 with a 5500R Series system interface, and Series IX software. The trimmed samples were positioned between two 1" flathead grippers outfitted with textured rubberized padding. Initial distance between jaws measured seven inches. Cross-head speed was set at 0.5 inch per minute, and the load cell was calibrated for a full scale load range of 224.809 lbf.

During each test, the cross-head movement is programmed to stop at the moment of material failure — whether hinge, adhesive, or painted support. The force required to create the failure is measured in pound-force per inch (lbf/in) or kilo-Newtons per meter (kN/m), and recorded for each sample. During operation, the lower cross head moved in a downward motion, drawing the painted newsprint support away from the hinge, which was held stationary at top. The cross heads return automatically to the initial distance of seven inches apart, the broken sample is removed, and the next sample is inserted.

4. RESULTS

After testing, all samples were examined and data were recorded according to TAPPI Test T 813 om-91, Tensile test for the manufacturer's joint of fiberboard shipping containers. Observations and calculations included type of failure, average load at failure with standard deviation, degree of oil saturation in sample, and experimenter's notes.

Of the forty tensile test separations, thirty resulted in adhesive failure, seven in hinge failure, and three in support failure (See fig.5). In most instances, it took less load to break the adhesive bond than to produce other failure types. Results reported in Table 1 list samples in order of increasing load-force (in kN/m and lbf/in) required to cause failure. Load forces at failure ranged from a low of 1.323 kN/m, for an adhesive failure, to a high of 2.778 for a support failure. The mean or average failure of all types was 2.010 kN/m; the mean adhesive failure measured 1.921 kN/m; the mean hinge failure, 2.142 kN/m; and the mean support failure, 2.585 kN/m. (See fig.6) This last value corresponds to industry tensile testing results, where at similar cross head speeds, 1" wide strips of commercially-manufactured, wood fiber-based paper typically undergo cohesive failure at loads from 14 to 15 lbf/in, or 2.452 to 2.628 kN/m. (Conklin 1998. Personal communication) [A published standard is not available]

In examination of the samples, it became evident that the degree of oil saturation is closely related to failure type and average load at failure (Table 6). Based on paint coverage, samples were divided into four classes of oil saturation: 1) full, 2) variegated, 3) low, and 4) negligible or none. The designation 'variegated' describes samples with an uneven paint application with three distinct zones: 1) oil saturation, usually full, directly associated with paint coverage, 2) oil haloing emanating from the painted region, and 3) plain, unpainted newsprint paper. In variegated samples, failure occurring in the wheat starch bond corresponds directly to painted surfaces, and is discerned

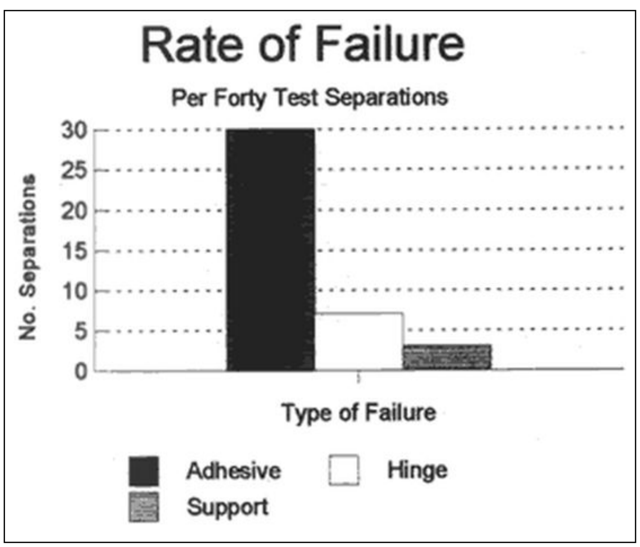

Fig. 5 Rate of failure per forty test separations - number of separations vs. type of failure

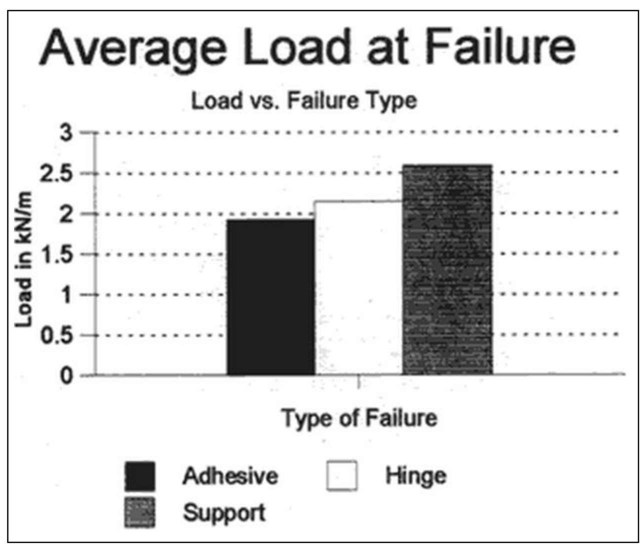

Fig. 6 average load at failure - load in kN/m vs. type of failure

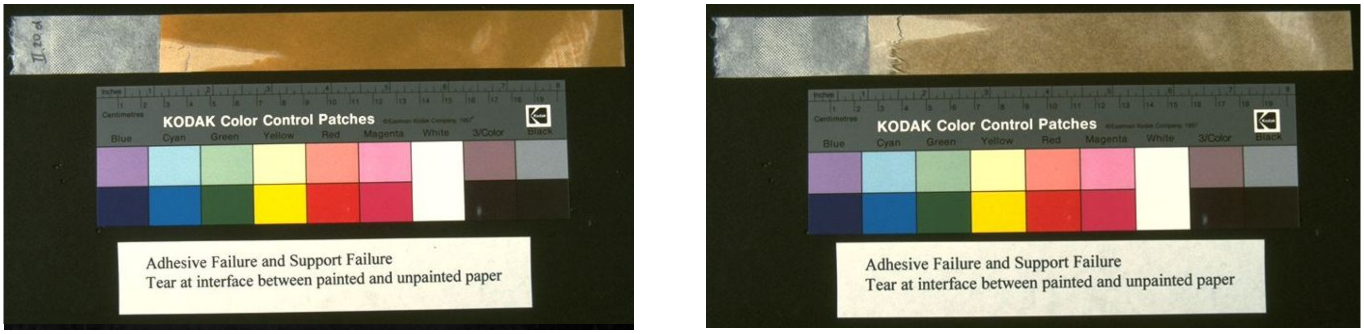

Fig. 7-8. Recto and verso of a variegated sample # II.20.d.. Failure occurring in the wheat starch bond corresponds directly to painted surfaces, and is discerned readily from intact bonds corresponding to unpainted surfaces

Fig. 9-10. Recto and verso of a sample # III.22.e. Full oil saturation corresponds with complete adhesive failure

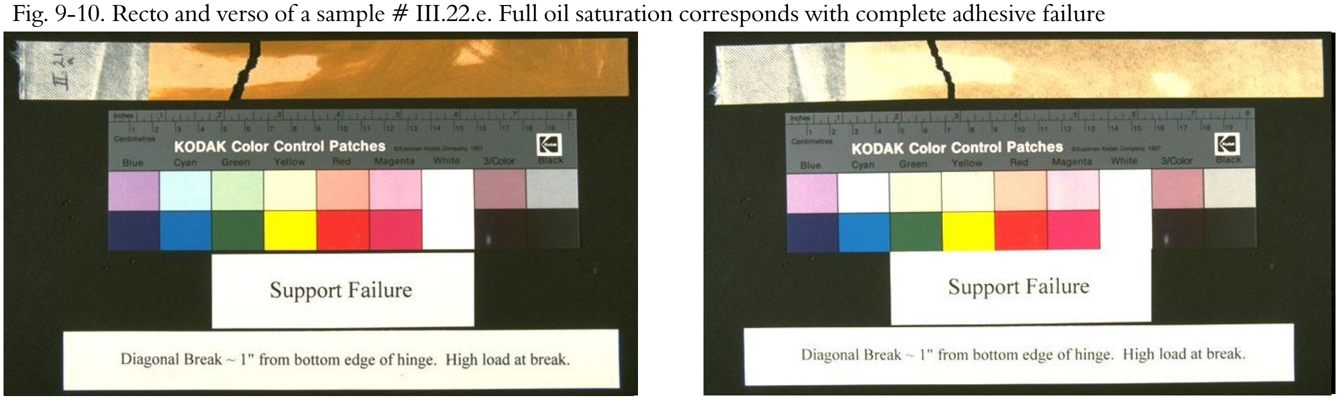

Fig. 11-12. Recto and verso of sample # II.21.a. Negligible oil saturation corresponds with support failure at high load

readily from intact bonds corresponding to unpainted surfaces (fig. 7-8).

When load was applied to oil-saturated samples (full and variegated), the lap/shear joint failed thirty out of thirty-three times. Adhesive failure clearly correlates with oil coverage. For example, in samples with full oil coverage, eight out of eight test pulls resulted in adhesive failure (fig. 9-10). In samples with variegated oil saturation, twenty-two out of twenty- five test pulls resulted in adhesive failure. This is in contrast to the seven samples with low to negligible oil saturation. In samples with low oil saturation, four out of five test pulls resulted in hinge failures; and one resulted in support failure (fig. 11-12). Lap/shear testing of the two samples with negligible or no oil saturation resulted in one hinge failure, and one support failure.

Each of the three support failures occurs in Yellow Ochre specimens. Ruptures take place within 1-2" from the upper edge of the support — from ~1/4" to 1" below the bottom edge of the hinge joint. At bonding sites, these supports range in degree of oil saturation: one is characterized as variegated, one as low, and one as negligible. Two of the three failures occur at high load forces: 2.726 kN/m (15.567 lbf/in) and 2.778 kN/m (15.862 lbf/in).

Test data reveal another consistent relationship between degree of oil saturation and average load at failure. As noted in Figure 13, the greater the oil saturation, the lower the average load at failure; and the lower the oil

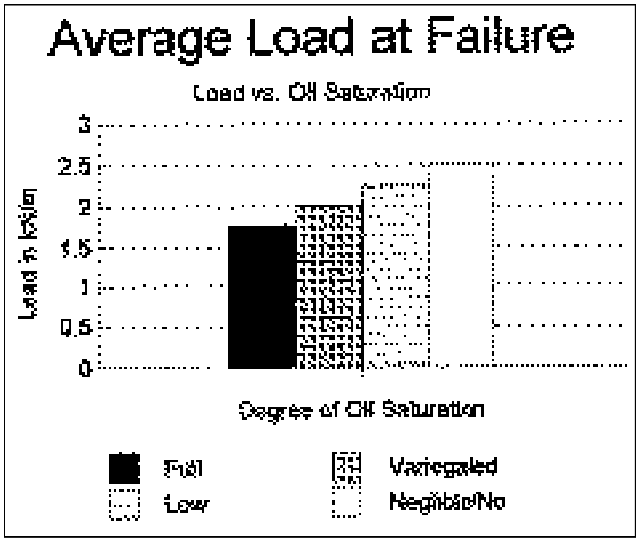

Fig. 13 Average load at failure - load in kN/m vs. degree of oil saturation

saturation, the greater the average load at failure. The average load at failure for full oil saturation is 1.763 kN/m; for variegated oil saturation: 2.003 kN/m; for low oil saturation: 2.237; and for negligible/no oil saturation: 2.509.

As demonstrated in Table 7 — Summary of Lap/Shear Tests of Wheat Starch Paste on Oil-Saturated Paper — loads at failure were greater on average for Yellow Ochre samples than for English Red Light samples. The combined average load at failure for Yellow Ochre samples, Groups I and II, amounts to 2.152 kN/m (12.285 lbf/in). The combined average load at failure for English Red Light samples, Groups III and IV, is 1.877 kN/m (10.715 lbf/in), a 12.8% decrease in load force.

Analysis of data in Table 7 — Summary of Lap/shear Tests of Wheat Starch Paste on Oil-Saturated Paper — revealed an inverse relationship between degree of dilution (thinning) of the paint and the average load at failure, measured in kN/m. In the Yellow Ochre samples, the average load at failure for paint straight out of the tube (group I) is 2.354 kN/m, while the load of the thinned paint samples (group II) averaged 2.778 kN/m. If this trend had been consistent, the English Red Light groups should follow the same pattern. However, for samples with paint straight out of the tube (group III), the average failure measured 1.786 kN/m, less than that of thinned paint samples (group IV) with an average load at failure of 1.967 kN/m.

This discrepancy prompted further investigation. Based on ultraviolet/visible fluorescence examination, it becomes apparent that paint straight out of the tube has a higher oil content than paint thinned with Winsor Newton painting medium (fig.14-18). The visible fluorescence reaction, a golden yellow hue, suggests that the addition of painting medium composed of stand oil and turpentine disperses the paint and produces a paint film with a lower oil content. Paint straight out of the tube is more concentrated, and thus, holds more oil. This observation is consistent with the behavior of groups III and IV.

Since the same trend does not occur with the Yellow Ochre samples it is likely to be due to a much lower degree of oil saturation. As seen in tables I and VII, four out of ten samples with paint straight out of the tube (group I), have a low oil saturation, and higher loads at failure — 2.103, 2.334, 2.360, and 2.726 kN/m. In future investigations, the oil saturation of the samples could be selected to be more consistent with other test groups.

Other observations include the frequency of ancillary damage to the specimens. From a group of thirty samples with adhesive failures, six — or 20% — also underwent

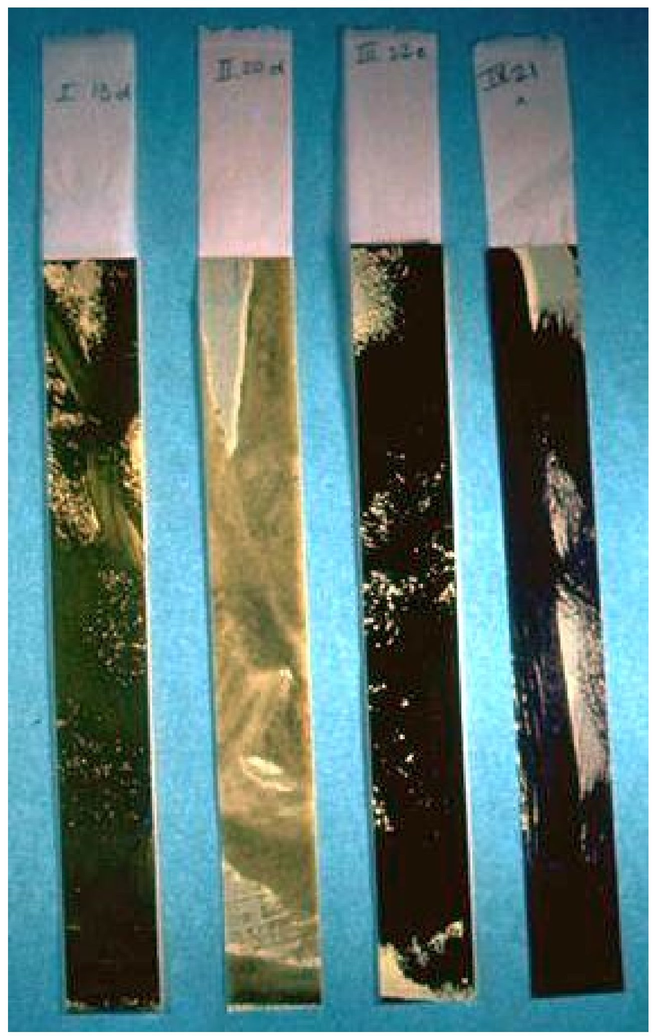

Fig. 14. UV/VIS Fluorescence. From left to right: Recto of samples I.13.d.- straight, II.20.d.- thinned, III.22.c.- straight, IV.21.a.- thinned

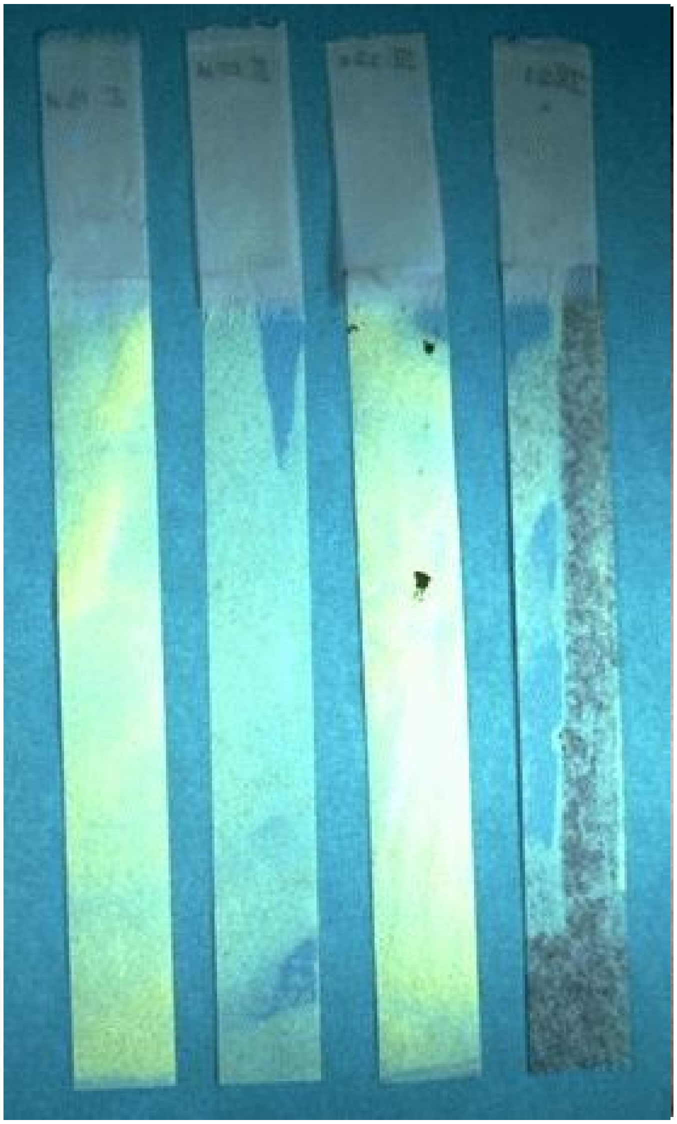

Fig. 15-16. UV/VIS Fluorescence. From left to right: Verso of samples I.13.d., II.20.d., III.22.c., IV.21.a. The more intense UV/VIS fluoresce reaction indicates that paint straight from the tube has a greater oil concentration than paint thinned with Winsor Newton oil painting medium

support failures (fig. 19-20); fifteen - or 50% -showed some stress on the hinge (fig. 21).

5. DISCUSSION

It is significant that 75% of all lap/shear tensile tests resulted in adhesive failure. Bonds were observed to break at loads from a low of 1.323 kN/m (7.554 lbf/in) to a high of 2.778 kN/m (15.862 lbf/in). These numbers have immediate relevance for weighty, large-scale works on paper where oil-saturated paper is to be — or has been for some time — held in shear with only a few hinges, particularly for those works being shipped upright in traveling exhibitions, for they may well be subjected to sudden downward jolts.

Results also show the unbalanced adhesive strengths of a wheat starch bond to aged and oil-saturated newsprint paper, relative to a bond made to aged, but unpainted, newsprint paper. The paste bond to oil-saturated paper fails at loads well below those of plain, unpainted paper, which, in all test pulls, remained intact.

In addition, it is clear that one type of damage can lead to another. Under lap/shear stresses, when adhesive joints fail, tears in the support may also occur. As mentioned above, six (or 20%) of the thirty test separations resulting in adhesive failures also produced tears in the newsprint support. On those six samples, the paint coverage is variegated, and the hinge/wheat starch bond covers both painted and unpainted paper. Ruptures occur where stresses are uneven. Vertical tears form in the well-adhered unpainted areas adjacent to the failed bonds of painted regions, and horizontal tears course along the bottom edge of hinges. This raises concerns for curators, conservators, and matter/framers alike, for the risk of additional injury to a work of art resulting

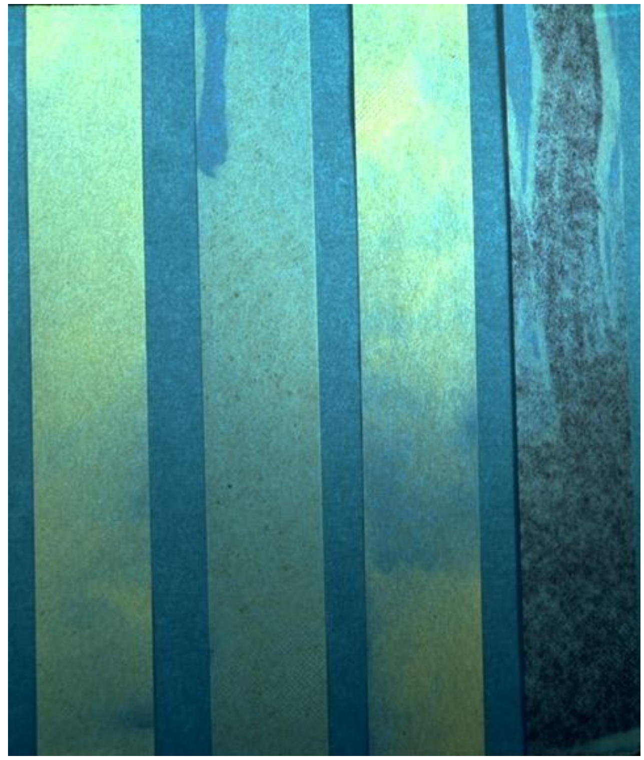

Fig. 17. (left) UV/VIS fluorescence. From left to right: recto of samples I.17.b.- straight, II.20.c.- thinned, III.21.d.- straight, IV.15.b.- thinned

Fig. 18. (above) UV/VIS fluorescence. From left to right: verso of samples I.17.b., II.20.c., III.21.d., IV.15.b. The more intense UV/VIS fluoresce reaction indicates that paint straight from the tube has a greater oil concentration than paint thinned with Winsor Newton oil painting medium

from poorly-placed or inadequately-adhered hinges, is both undesirable and avoidable.

Other considerations in hinging such works include the cohesive strength of oil films, and the relationship of paper strength to specific pigments in oil. As noted above, all three support failures occurred in Yellow Ochre samples. It is difficult to state confidently whether these failures are the result of low oil-saturation or pigment type. However, there appears to be a correlation between pigment type and load force at failure. The average load at failure for Yellow Ochre samples, Groups I and II, is 2.154 kN/m (12.285 lbf/in), and that of the English Red Light samples, Groups III and IV, is lower — 1.877 kN/m (10.715 lbf/in).

The greater tenacity of the Yellow Ochre samples, relative to English Red Light specimens, seems associated to unique physical properties of the Yellow Ochre in linseed oil. As a hydrate of iron oxide, the pigment binds well to oil, and produces a tough, good-to-excellent, paint film. English Red Light, on the other hand, actually powders and sheds, indicating a less-integrated, weaker paint film. Due to factors such as oil index, wettability, drying rate, and pH range, conservators would expect to encounter differences in adhesive bonding and paper durability, relative to pigment type, in oil paintings on paper.

6. CONCLUSION

Results indicate the inadequacy of wheat starch bonding to aged and oil-saturated newsprint paper when paste is prepared in a 1:4.5 ratio and thinned with distilled water. Ultimately what is adequate for plain paper does not appear acceptable for oil-saturated paper.

Accordingly, conservators may wish to inspect works of art on display or in storage to assess the condition of the hinge bonds.

Further testing is indicated. Proposals for future investigation would include examination of a range of other adhesive formulations, such as more concentrated starch-to-water mixtures, starch paste in combination with other adhesives, cellulose ethers, other synthetic adhesives such as Lascaux acrylic dispersions, vinyl acetate emulsions, and resin mixtures such as Beva 371.

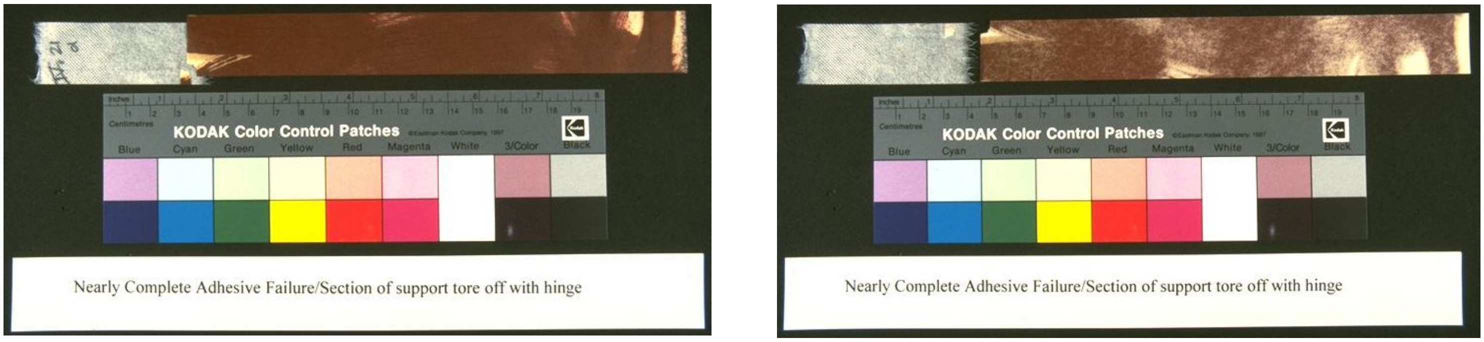

Fig. 19-20. Recto and verso of sample # IV.21.d. Adhesive failure with corresponding support failure

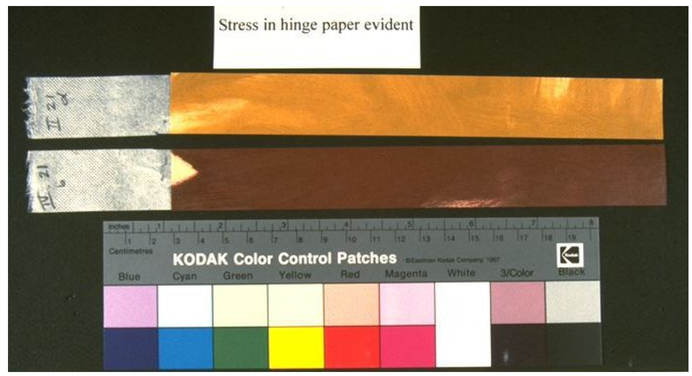

Fig. 21. Top: sample # II.21.d. Bottom: sample # IV.21.b. Adhesive failure corresponds with oil saturation. Wheat starch paste bond to unpainted paper remains intact

7. ACKNOWLEDGMENTS

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SUPPLIERS

Blotter Paper
Archivart Products
7 Caesar Place
P.O. Box 428
Moonachie, New Jersey

Fletcher brand table mat cutter # 2100
United Picture Framing Wholesales
Long Island, New York

Hinge Tissue
Hiromi HPO7, Sekishu Hanshi-mare
New York Central Art Supply
62 Third Avenue
New York, New York 10003

Hollytex Polyester Webbing
Tefal Cook & Stir Gravy/Paste Maker
University Products
517 Main Street
P.O. Box 101
Holyoke, Massachusetts 01041-0101

Humidity Indicator Strips
Multiform Desiccant Products, Inc.
Buffalo, New York 14213

Morilla™ Newsprint Paper by Canson
Utrecht Oil Paints
Winsor Newton Oil Painting Medium
Utrecht Art Supply
111 Fourth Avenue
New York, New York 10003

Zin Sho fu wheat starch
TALAS
568 Broadway
New York, New York 10012

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This article has been modified from its original version. Text and figures have been updated from source material to create more legible content. Arrangement has remained unchanged. 2018

Table 1. Lap/Shear Test Results—All Samples

	kN/m	lbsf/in	Paint	Type of Failure	Oil Saturation	Other failure
1	1.323	7.554	▲	A	Full	No
2	1.477	8.434	△	A	Full	No
3	1.482	8.460	■	A	Full	No
4	1.527	8.718	△	A	Variegated	Support
5	1.583	9.038	■	A	Full	No
6	1.618	9.241	△	A	Variegated	Stress on hinge
7	1.648	9.413	▲	A	Variegated	No
8	1.648	9.413	▲	A	Variegated	Support
9	1.660	9.478	■	H	Low	No
10	1.668	9.525	■	A	Full	No
11	1.714	9.788	■	A	Variegated	Stress on hinge
12	1.778	10.154	△	A	Variegated	Stress on hinge
13	1.782	10.176	■	A	Variegated	Support
14	1.788	10.211	△	A	Variegated	No
15	1.814	10.360	△	A	Variegated	Support
16	1.861	10.626	■	A	Variegated	Stress on hinge
17	1.872	1.0.688	▲	A	Variegated	Stress on hinge
18	1.895	10.823	▲	A	Variegated	Stress on hinge
19	1.942	11.091	■	A	Full	No
20	1.945	11.108	▲	A	Variegated	Stress on hinge
Σ	34.025	194.299	■			

Table 1. Lap/Shear Test Results - All Samples

Table 1 continued. Lap/Shear Test Results—All Samples

	kN/m	lbsf/in	Paint	Type of Failure	Oil Saturation	Other failure
21	2.009	11.469	■	H	Variegated	Slight adhesive
22	2.103	12.007	□	H	Low	No
23	2.134	12.188	△	A	Variegated	Stress on hinge
24	2.163	12.351	■	A	Variegated	Stress on hinge
25	2.167	12.371	▲	A	Variegated	Stress on hinge
26	2.199:	12:556	△	A	Variegated	Stress on hinge
27	2.240	12.792	▲	H	Negligible/None	No
28	2.252	12.860	□	S	Variegated	No
29	2.262	12.914	□	A	Variegated	Stress on hinge
30	2.274	12,985	□	A	Full	No
31	2.289	13.071	□	H	Variegated	No
32	2.334	13.329	□	H	Low .	Slight adhesive
33	2.344	13.384	▲	A	Variegated	Stress on hinge
34	2.358	13.465	□	A	Full	Stress on hinge
35	2.360	13.475	□	H	Low	No
36	2.375	13.561	△	A	Variegated	Support
37	2.416	13.798	□	A	Variegated	Stress on hinge
38	2.584	14.753	▲	A	Variegated	Support
39	2.726	15.567	□	S	Low	No
40	2.778	15.862	△	S	Negligible/None	No
Σ	80.392	459.046				
Mean	2.010	11.476				
Median	1.977	11.289				

KEY: □=Ochre Straight ■=English Red Light Straight
△=Ochre Thinned ▲=English Red Light Thinned

KEY: kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 1 continued. Lap/Shear Test Results - All Samples

Ochre Straight

Table 2. Lap/Shear Test Results—Ochre Straight

	Sample No.	Min	lbsf/in	Type of Failure	Oil Saturation
22	I. 13. a	2.103	12.007	H	Low
28	I. 13. b	2.252	12.860	S	Variegated
29	I. 17. d	2.262	12.914	A	Variegated
30	I. 9. b	2.274	12.985	A	Full
31	I. 13. d	2.289	13.071	H	Variegated
32	I. 17. a	2.334	13.329	H	Low
34	I. 17. b	2.358	13.465	A	Full
35	I. 17. a	2.360	13.475	H	Low
36	I. 17. c	2.416	13.798	A	Variegated
39	I. 9. e*	2.726	15.567	S	Low
Σ		23.374	133.651		
Mean		2.337	13.361		
Median		2.312	13.200		
SD		0.161			

* Note: When this sample was run, test grippers were positioned closer to the top edge of the support than in other samples. It was included to complete the sample set of ten. Had it not been included, the mean would be 2.294 Min, a difference of 0.043.

KEY: kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 2. Lap/Shear Test Results - Ochre Straight

▲Ochre Thinned

Table 3. Lap/Shear Test Results—Ochre Thinned

Sample No.	kN/m	lbsf/in	Type of Failure	Oil Saturation	
2	II. 10. d	1.477	8.434	A	Full
4	II. 20. d	1.527	8.718	A	Variegated
6	II. 20. b	1.618	9.241	A	Variegated
12	II. 10. b	1.778	10.154	A	Variegated
14	11. 10. c	1.788	10.211	A	Variegated
15	II. 20. a	1.814	10.360	A	Variegated
23	II. 20. c	2.134	12.188	A	Variegated
26	II. 21. d	2.199	12.556	A	Variegated
36	II. 21. c	2.375	13.561	A	Variegated
40	II. 21. a	2.778	15.862	S	Negligible/None
Σ		19.488	111.285		
Mean		1.949	11.129		
Median		1.801	10.285		
SD		0.411			

KEY: kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 3. Lap/Shear Test Results - Ochre Thinned

English Red Light Straight

Table 4. Lap/Shear Test Results—English Red Light Straight

Sample No.	kN/m	lbsf/in	Type of Failure	Oil Saturation	
3	III. 22. c	1.482	8.460	A	Full
5	III. 22. d	1.583	9.038	A	Full
9	III. 21. a	1.660	9.478	H	Low
10	III. 21. d	1.668	9.525	A	Full
11	III. 21. c	1.714	9.788	A	Variegated
13	III. 22. a	1.782	10.176	A	Variegated
16	III. 21. a	1.861	10.626	A	Variegated
19	III. 22. a	1.942	11.091	A	Full
21	III. 21. b	2.009	11.469	H	Variegated
24	III. 22. b	2.163	12.351	A	Variegated
Σ		17.864	102.002		
Mean		1.786	10.200		
Median		1.748	9.982		
SD		0.209			

KEY: kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 4. Lap/Shear Test Results - English Red Light Straight

▲English Red Light Thinned

Table 5. Lap/Shear Test Results—English Red Light Thinned

	Sample No.	kN/m	lbsf/in	Type of Failure	Oil Saturation
1	IV. 15. d	1.323	7.554	A	Full
7	IV. 21. a	1.648	9.413	A	Variegated
8	IV. 21. d	1.648	9.413	A	Variegated
7	IV. 21. c	1.872	10.688	A	Variegated
8	IV. 15. b	1.895	10.823	A	Variegated
0	IV. 21. a	1.945	11.108	A	Variegated
5	IV. 21. b	2.167	12.371	A	Variegated
7	IV. 15. c	2.240	12.792	H	Negligible/None
3	IV. 17. a	2.344	13.384	A	Variegated
8	IV. 16. a	2.584	14.753	A	Variegated
Σ		19.666	126.997		
Mean		1.967	12.670		
Median		1.920	10.965		
SD		0.375			

KEY: kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 5. Lap/Shear Test Results - English Red Light Thinned

Degree of Saturation				
Type of Failure	FULL	VARIEGATED	LOW	NEGLIGIBLE/NONE
Adhesive	8	22	0	0
Hinge	0	2	4	1
Support	0	1	1	1
Total	8	25	5	2

Table 6. Correlation between Oil Saturation and Bond Failure

	MIN kN/m	MAX kN/m	AVERAGE kN/m	MEDIAN	# Failures A—H—S	SD	Oil Saturation F—V—L—N
ALL SAMPLES	1.323	2.778	2.010	1.977	30—7—3	.361	8—25—5—2
■YELLOW OCHRE STRAIGHT	2.103	2.726	2.354	2.314	4—4—2	.161	2—4—4—0
▲YELLOW OCHRE THINNED	1.477	2.778	1.949	1.801	9—0—1	.411	1—8—0—1
■ENGLISH RED LIGHT—STRAIGHT	1.482	2.163	1.786	1.748	8—2—0	.209	4—5—1—0
▲ENGLISH RED LIGHT - THINNED	1.323	2.584	1.967	1.920	9—1—0	.375	1—8—0 -1

KEY: ■=Ochre Straight ■=English Red Light Straight
▲=Ochre Thinned ▲=English Red Light Thinned

kN/m=kilo-Newtons per meter lbsf/in=pounds-force/inch
Type of Failure: a=Adhesive h=Hinge s=Support

Table 7. Summary of Lap-Shear Tests of Wheat Starch Paste on Oil-Saturated Paper