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Comparison of Klucel G Pre-made Mending Tissue Using Isopropanol and Ethanol and Three Methods of Reactivation

1. ABSTRACT

Two solutions of Klucel G adhesive were made, one with isopropanol and one with ethanol. The mending tissue was made by applying the adhesive to a 10 g kozo fibre Japanese tissue. The adhesives were reactivated using one of three methods of reactivation: brush application of the solvent, solvent vapour, and heat. The tissue sample with the reactivated adhesive was adhered to another tissue sample. Bond strength was determined with the T-Peel Test and the Lap Joint Shear Strength Test according to American Society for Testing Materials (ASTM) standards. The force needed to break the sample or pull it apart (depending on the test) was recorded. Klucel G was dyed with a Procion MX dye and additional samples were prepared as previously described. Sample cross sections were then examined under a microscope to see how far the adhesive penetrated into the tissue. There was no correlation between the solvent used to make the adhesive and the bond strength. Using isopropanol to reactivate the adhesive produced the strongest bond. The direct application of the solvent with a brush made the strongest bond. The microscopy results support the tensile testing data because the isopropanol reactivation and the direct application of the solvent caused a deeper penetration of the adhesive which corresponds to the stronger bond produced.

2. INTRODUCTION

The inspiration for this research came in summer 2013 while interning at the Harry Ransom Center at the University of Texas at Austin. There, a letter written in iron gall ink was treated that had tears and a loss that went right through areas with ink on them. Since the iron gall ink was water sensitive, wheat starch paste mends were not considered as a treatment. An adhesive was needed that could be dissolved in a solvent, so the iron-gall ink would not be affected by the mends. One option was to use Klucel G dissolved in a polar organic solvent. It was decided that Klucel G would be used with isopropanol to make pre-made mending tissue for this object. Although isopropanol was used in this instance, other solvents can be used with Klucel G. After research and consulting other conservators, it was determined that ethanol was the other most common solvent used with Klucel G, so it will be used to compare to isopropanol (Hamilton 2013, G. Hill 2013).

The solvent reactivation technique used in the treatment of the letter was direct application of the solvent to the pre-made mending strip with a brush. The direct application technique seemed to work well for this treatment, but there are other methods that should be considered. Jessica Régimbald used solvent vapour to reactivate the adhesive for her Queen's

University Master of Art Conservation Research Project (Régimbald, 2013). Klucel G can also be reactivated with heat (Hercules Inc. 2001).

2.1. ADHESIVE

"Klucel hydroxypropyl cellulose is a non-ionic water soluble cellulose ether with a versatile combination of properties" (Hercules Inc. 2001). The adhesive is produced in multiple types that are labelled with letters F, H, M, G, J, L, and E. These products differ in their molecular weight and viscosity. Klucel is very flexible and does not become tacky in high humidity. In most cases, the more polar the solvent the better the solution will be (Hercules Inc. 2001). The structure of hydroxypropyl cellulose can be seen in figure 1.

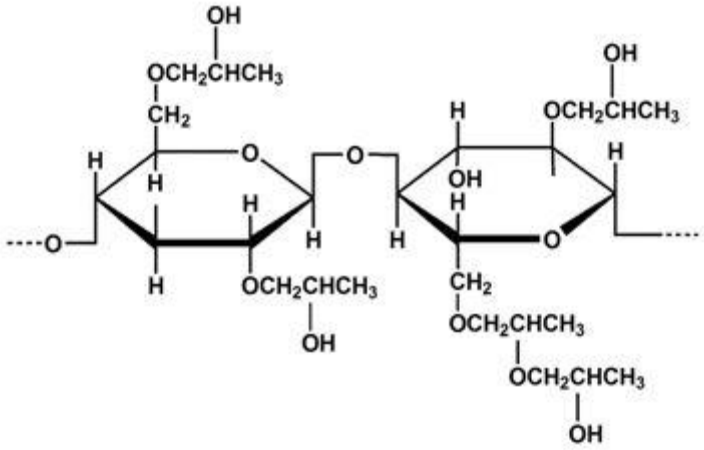

Fig. 1: Hydroxypropyl cellulose

Klucel G is used instead of other grades of Klucel for conservation because of its favourable properties, such as its medium viscosity. It dries clear and is soluble in water and other polar solvents (Horie 2010).

Since Klucel G can be used with polar organic solvents, like ethanol, it is suitable for objects with water-sensitive media, such as iron-gall ink. This type of material is less likely to cause tidelines or cockling around the mended area than a repair made with wheat starch paste and water (Anderson and Reidell 2009).

2.2. STABILITY

When working with adhesives that will come into contact with paper objects, their stability is always of concern to conservators. When Klucel became available, it was important to determine its stability. The Getty Conservation Institute (GCI) published an extensive paper in 1990 that described their research into cellulose ethers that included

Klucel. They tested many aging properties of the different grades of Klucel using artificial aging and found that Klucel G was the most stable. The material did not demonstrate any darkening with age, whether mixed with water or ethanol (Feller and Wilt 1990).

The extensive research done by the GCI was a good starting point for proving that Klucel G was stable enough for use in conservation, but it is always beneficial to support artificial aging results with natural aging research (Horie 2010). Therefore, it is fortunate that there are also cases of the natural aging of Klucel G that come with positive results. There was a poster presented at the Adhesive and Consolidant Symposium at the Canadian Conservation Institute (CCI) in 2011 that described hinging treatments at the Atelier de Conservation et de Restauration des Photographies de la Ville de Paris (ARCP). A group of 228 photographs and prints had been hinged with Klucel G in ethanol between 1989 and 2006. These treatments had aged naturally for 6 to 22 years and only two of them exhibited partial adhesion loss, which was attributed to poor original application, not the integrity of the adhesive. Some of the photographs had slight yellowing, but this was not attributed to the aging of the adhesive because it was not consistent over all of the objects. The naturally aged Klucel G also proved to be easily reversible when some of the photographs were remounted for exhibition (Sirven et al. 2011, Régimbald 2013).

Klucel G has been thoroughly investigated and it performed well in both artificial and natural aging studies. Due to the existing research of the aging and stability of Klucel G, artificial aging will not be performed in this experiment.

2.3. PRE-MADE REPAIR MATERIALS

Pre-made mending tissues have many uses in paper conservation. They allow you to make a large quantity at once that can be used as needed later, which ultimately saves time. Pre-made mending tissues are also very useful when performing batch treatments because the adhesive only has to be reactivated and it is ready to use. They widen the possibilities of the type of repair tissue as well. Some tissues are too thin to apply the adhesive directly, so laying the delicate tissue onto the wet adhesive is preferable (Anderson and Reidell 2009).

2.4. RESEARCH GOALS

The goal of this research will be to determine whether ethanol or isopropanol in Klucel G makes the strongest pre-made mending tissue bond. This research will also determine whether direct application of the solvent, solvent vapour, or heat makes a stronger bond upon reactivation of the adhesive. This would standardize the preparation of mending tissues, so

conservators would no longer need to guess about what solvent or reactivation technique to use.

2.5. RESEARCH QUESTIONS

In order to determine which solvent makes the strongest adhesive solution and which reactivation method makes the strongest bond, the following questions must be answered:

- Would using different solvents to prepare the adhesive affect the adhesive strength of Klucel G?
- Do different solvents used to reactivate Klucel G affect the depth of adhesive penetration into the tissue and the strength of the bond?
- Does the method of reactivation of the adhesive affect its strength?

3. EXPERIMENTAL

3.1. MATERIALS

3.1.1. Solvent Type

Solvents were used in this research to make Klucel G because they could be used on objects with water-sensitive media. Research and discussion with conservators showed that different solvents could be used to make Klucel G, but two solvents were used most often. The two solvents chosen for this research were anhydrous ethyl alcohol (ethanol) and isopropanol. They have similar properties although ethanol is slightly more volatile than isopropanol. The formula for ethanol is CH_3CH_2OH. Its molecular weight is 46.07 and its evaporation rate is 1.7. The formula for isopropanol is $CH_3CH(OH)CH_3$. Its molecular weight is 60.10 and its evaporation rate is 1.5. The evaporation rates are based on the standard where the evaporation rate of butyl acetate = 1 and anything higher than that evaporates faster than butyl acetate and anything lower evaporates slower (ASTM 2011). Therefore, ethanol evaporates slightly faster than isopropanol.

3.1.2. Substrate

Kizukishi Japanese tissue was chosen as the substrate for this experiment because it was a 100% kozo fibre tissue. Kozo fibre tissues are very strong due to their long fibres. The 10 g Kizukishi tissue used in this project was purchased from Talas.

3.1.3. Methods of Reactivation

The three methods of reactivation chosen were solvent applied with a brush, solvent vapour delivered through a Gore-tex humidity tent, and heat applied with a tacking iron. These were chosen because they are common methods of reactivating the adhesive of pre-made mending tissues (Anderson and Reidell 2009).

3.2. ADHESION TESTING

The mending tissue was prepared using Klucel G in ethanol or isopropanol. Three sheets of mending tissue were made with an 8% w/v solution of Klucel G in ethanol and three sheets were made with an 8% solution of Klucel G in isopropanol. For the two solutions, the three sheets were each cut into 10 samples, producing 30 samples per adhesive solvent. 10 samples were reactivated with brush application of the solvent, 10 were reactivated with solvent vapour, and 10 were heat reactivated. This procedure was done twice, once for the T-Peel Test and once for the Lap-Joint Shear Strength Test (LJSS), producing 60 samples per test, which resulted in 120 samples. Six additional samples were made from the pre-made tissues to be analyzed with microscopy to compare how the type of solvent used and the reactivation methods affect the depth of penetration of adhesive. This brought the total number of samples to 126, which is illustrated in figure 2.

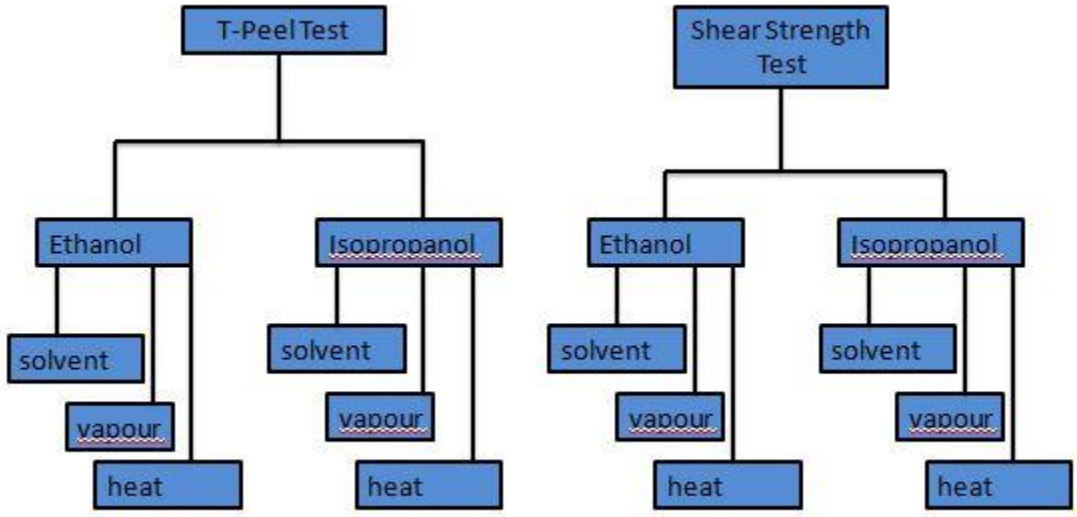

Fig. 2: Sample flowchart

An 8% solution was chosen because preliminary testing demonstrated that it made a strong bond and concentrations lower than that did not produce a secure enough bond (Régimbald 2013). The 8% solution also has a thick consistency that allows it to be spread easily. The adhesive solution was applied to sheets of Mylar using a draw-down method to produce an even layer of adhesive the size of the adhesive area required by the tensile testing standards. The tissue was then laid on the adhesive while being careful not to make any air bubbles between the adhesive and the tissue. A brayer, 141.8 g and 10 cm wide, was passed over the tissue twice while applying no additional pressure to ensure that there was good contact between the tissue and the adhesive. These sheets were allowed to dry for four days, removed from the Mylar, cut to size, and weighed. Three random samples were weighed every day for the next four days to ensure the weights remained constant to determine that there was no solvent left in the adhesive.

The Klucel G adhesive was made using 16 g of Klucel G powder with 200 mL of solvent to make an 8% solution. The solvent was stirred constantly with a magnetic stirrer at 300 rpm while the Klucel G powder was slowly added. Once the solution began to gel and the stirrer stopped moving the solution was stirred by hand using a glass rod while the rest of the powder was added. This solution was allowed to sit overnight to ensure all of the Klucel G was dissolved.

Next, the draw-down templates were made using silicon release Mylar and electrical tape. The length of the adhesive area was measured out onto the Mylar and two strips of electrical tape were put down at the measurements. For the Lap-Joint Shear Strength Test the two strips of electrical tape were 17 mm

Fig. 3: Draw-down (courtesy of Emily Turgeon-Brunet)

apart. For the T-Peel test the electrical tape was 75 mm apart. The tissue paper was cut into 10 cm wide strips. The adhesive was drawn down the templates using a glass microscope slide that was held at a 45° angle. The draw-down method can be seen in figure 3. While the adhesive was still wet the tissue strip was laid on the adhesive. A brayer was rolled over the tissue twice to ensure good contact of the tissue to the adhesive. The template was set aside to dry for four days, although the adhesive appeared to be dry within 30 minutes. Then, the tissue samples were taken off the templates and cut into 25 mm wide strips. 120 non-adhesive samples were then cut at 25 mm wide and 100 mm long. The samples were prepared for each method of reactivation.

The heat reactivation was performed with a Bienfang Adjustable Tacking Iron set at one cm past the medium heat setting, which was hot to touch. The adhesive sample was arranged adhesive-side-up with a non-adhesive sample placed on top. The iron was set on the sample with a weight on top of it for two minutes. The combined weight of the iron and the weight was 996.6 g. Once reactivated, the sample was set aside to cool.

The solvent reactivation was performed with the appropriate solvent and a soft brush. Each adhesive sample was placed on a piece of Mylar, the brush was dipped in the solvent for 5 seconds, the brush was wiped on the side of the solvent beaker once to remove excess solvent, and the brush was passed over the adhesive area once. The non-adhesive sample was placed on the reactivated adhesive and the cold iron and weight was placed on the two pieces of tissue for two minutes and set aside to dry.

The solvent vapour reactivation was performed using a Gore-tex blotter stack because this would accommodate ten samples to be reactivated at once. The stack was formed from the bottom up with a piece of blotter, Reemay, the adhesive sample which was adhesive-side-up, Reemay, Gore-tex, solvent soaked blotter, and Mylar with weights around the perimeter. The samples were left in the stack for one hour, taken out, and adhered to non-adhesive samples with the cold iron and the weight left on for two minutes. The samples were set aside to dry.

The tensile testing was performed on an Instron 3365 tensile testing machine with the help of Paul Begin at the CCI in a room that meets the Technical Association of the Pulp and Paper Industry (TAPPI) standards for climate control. The testing room was environmentally controlled at 50% RH and 23° C. The samples were delivered to the TAPPI room, taken out of the container, and set on the table to acclimatize to the environment. After the samples had three days to acclimatize, all of the tensile testing was done over the course of one day.

3.2.1. Lap Joint Shear Strength (LJSS) Test

This test demonstrated if there was a difference in the strength of adhesion between the Klucel G solutions made with ethanol or isopropanol. It was also used to test the difference in strength between the three methods of reactivation.

The LJSS test evaluated the strength of the adhesive by putting a uniform load of 80 to 100 kg/cm² across the bond area at 1.33 mm/minute and determined the force needed to pull the two pieces of tissue apart (ASTM 2010). This data gave an accurate comparison between the strength of the adhesives.

Fig. 4: LJSS sample in the tensile tester

The samples for this test were prepared using the single lap-joint configuration because it imitated the repair of a "scarfed" tear in a paper object, where the paper was torn with overlapping edges. This sample can be seen in figure 4 at right.

The single lap-joint samples were made with two strips of Kizukishi tissue, measuring 100 mm by 25 mm in size which is illustrated in figure 5 (ASTM 2010). Strips were cut from the pre-made tissue with a scalpel using a 25 mm wide glass microscope slide as a template for consistency. The adhesive area was reactivated using one of the three reactivation methods and it was adhered to a plain tissue sample.

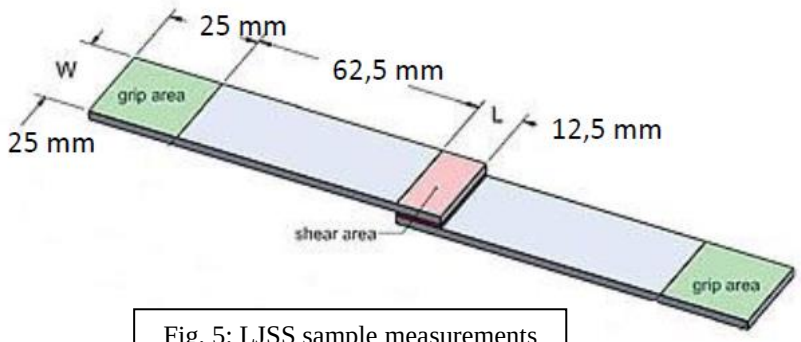

Fig. 5: LJSS sample measurements (ASTM 2010)

The ends of the samples were inserted into the grips of the tensile testing machine. The load was applied until the sample failed and the load and nature of the failure was recorded.

The nature of the failure was described using Jane Down's description of joint failures that is illustrated in figure 6 below.

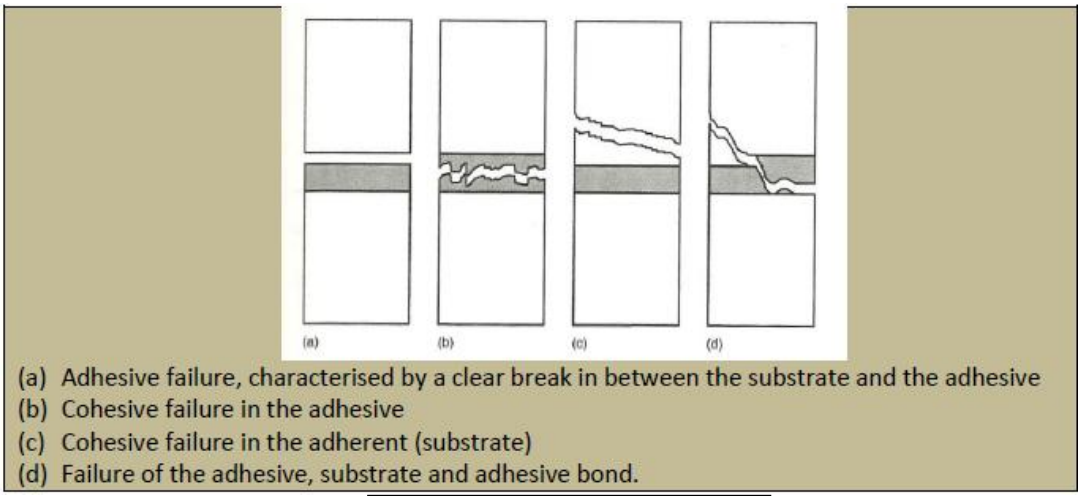

Fig. 6: Joint failure (Horie 2010)

3.2.2. T-Peel Test

The T-Peel test was carried out as an additional test of the adhesives' strength. The pre-made mending tissue sheets were used to make the samples for this test. The sheets were used to produce 60 strips of the Klucel G in isopropanol and Klucel G in ethanol tissues. These strips measured 25 mm wide and 100 mm long. A 25 mm wide microscope slide was used as a template. One adhesive strip and one plain tissue strip were adhered together by reactivating the adhesive along 75 mm of the length to make 60 samples, 20 of which were reactivated with solvent, 20 with solvent vapour, and 20 with heat. The samples looked like the image in figure 7 below.

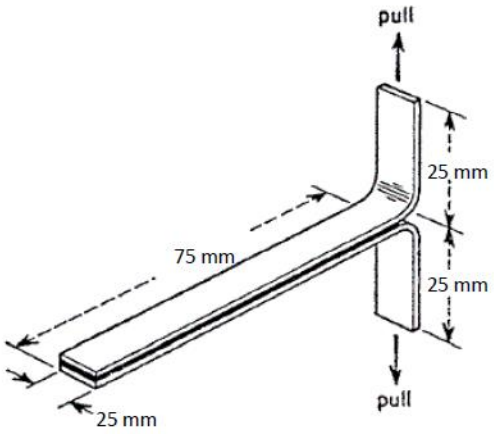

Fig. 7: T-Peel test measurements (ASTM 2008)

During testing, the unadhered ends of the samples were clamped in the grips of the tensile testing machine. The force was applied at a constant rate of 254 mm/minute (ASTM 2008). The peel resistance data was taken during the test as well as the nature of the sample failure.

3.2.3. Microscopic Analysis

An evaluation of the adhesives' diffusion into the tissue was done by examining cross sections of the samples under a microscope. A Procion MX textile dye was used to make the adhesive more visible to clearly evaluate how deep the adhesive penetrated into the tissue. This gave an indication of how strong the bond was between the adhesive and the tissue. A solution was made using 6.4 g of Klucel G, 0.64 g Procion MX Medium Blue dye, 6.4 g anhydrous sodium carbonate, and 1920 mL of deionized water. This solution was stirred constantly for 48 hours with a magnetic stirrer. The solution was pipetted into a dialysis tube that was sealed at one end. Once filled, the other end of the tube was sealed. This tube was put in a beaker of deionized water to allow any unbonded dye to pass through the dialysis tubing. This can be seen in figure 8 below.

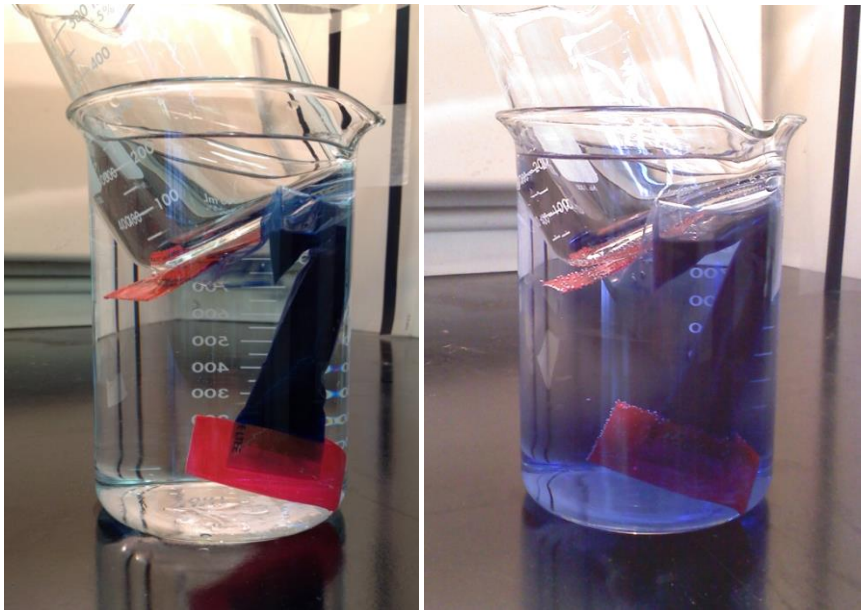

Fig. 8: Dialysis tube in beaker of deionized water on left and after some dye has come out on right

The deionized water in the beaker was changed every morning and evening until it no longer turned blue indicating that all of the unbonded dye was removed. This solution was lyophilized. Lyophilization is the freeze-drying of a solution to remove all the water. The liquid Klucel G solution was poured into plastic centrifuge tubes with screw-on lids. These tubes were frozen in either a conventional freezer or with liquid nitrogen. Once frozen, they were placed in the lyophilizer and all of the water was removed. The dry dyed Klucel G was used to make two 8% solutions of Klucel G in ethanol and isopropanol (fig. 9) that was used to make samples for the microscopic analysis.

Three samples were prepared for each type of solution and reactivation method for a total of six samples that were analyzed with microscopy. Cross sections were made from these samples and mounted on a microscope slide with Cargille Meltmount. Photomicrographs were taken to clearly demonstrate the results.

Fig. 9: Dyed Klucel G adhesive solutions

4. RESULTS

4.1 LAP-JOINT SHEAR STRENGTH TEST

The data for the LJSS Test performed with samples made from Klucel G in ethanol and Klucel G in isopropanol can be seen below in table 1, as well as the substrate tensile strength. These samples were prepared as described in the Experimental section above. The table shows the maximum force (kgf) that was exerted to break the samples.

Sample #	Maximum load (kgf)						
	Ethanol			Isopropanol			Substrate
	Solvent	Heat	Vapour	Solvent	Heat	Vapour	
1	3.539	1.541	0.474	3.390	1.021	0.499	3.500
2	2.970	1.224	0.263	3.305	1.665	2.964	3.347
3	3.587	0.225	0.912	3.894	0.982	2.956	3.331
4	2.742	1.540	1.538	3.248	1.009	3.015	3.875
5	2.869	0.987	0.728	3.379	0.428	3.845	3.679
6	3.033	1.046	1.576	3.386	1.731	3.004	3.752
7	3.582	1.812	2.697	3.638	1.509	2.481	3.772
8	3.019	1.384		3.137	0.460	0.773	2.886
9	2.662	1.555		3.626	1.326	3.079	4.074
10	2.992	1.820		2.970	1.275	3.240	3.314
Coefficient of variation	11.150	36.267	71.532	7.841	39.636	41.864	9.728
Maximum	3.587	1.820	2.697	3.894	1.731	3.845	4.074
Mean	3.100	1.313	1.170	3.397	1.141	2.586	3.553
Median	3.006	1.462	0.912	3.382	1.148	2.984	3.589
Minimum	2.662	0.225	0.263	2.970	0.428	0.499	2.886
Range	0.924	1.595	2.434	0.924	1.303	3.346	1.188
Standard deviation	0.34561	0.47631	0.83677	0.26637	0.4521	1.08246	0.34563

Key	
cohesive failure of the substrate	
adhesive failure	
adhesive and substrate failure	

Table 1: Maximum load for the LJSS test and the tensile strength of the substrate

Three of the ethanol vapour reactivated samples were not included in the testing because the adhesive failed before they were loaded into the testing machine.

The tensile strength of the substrate is also included in table 1. The tensile strength of the tissue was taken to compare to the LJSS test samples that were reactivated with brushed on solvent. These samples all broke within the substrate, so essentially the results were the tensile strength of the tissue.

Figure 7 shows the averaged results for all the LJSS tests. This serves as a comparison between the two adhesive mixtures, Klucel G in ethanol and Klucel G in isopropanol, and a comparison between the three methods of reactivation.

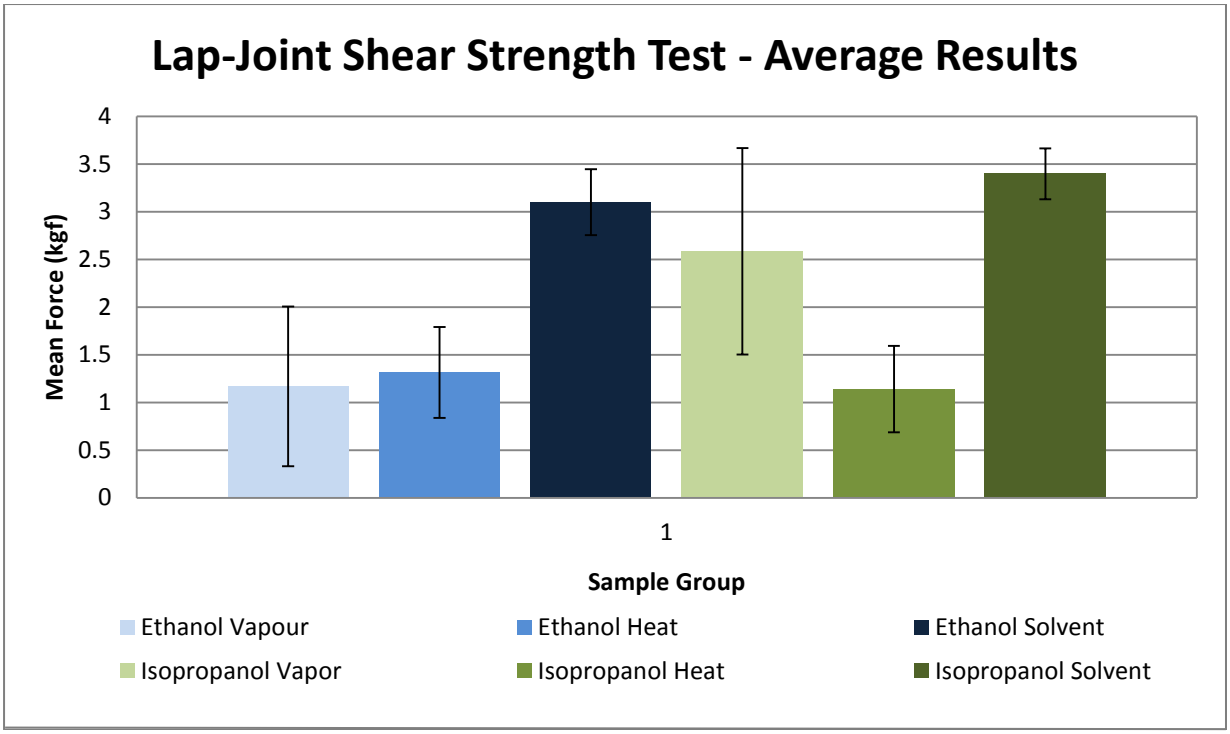

Fig. 7: Lap-Joint Shear Strength Test- Average Results

4.2 T-PEEL TEST

The data for the T-Peel Test performed with samples made from Klucel G in ethanol and Klucel G in isopropanol can be seen below in table 2. These samples were prepared as described in the Experimental section above. The results show the maximum force (kgf/25 mm) that was exerted to peel apart the samples. It also shows the average load (kgf/25 mm) exerted on the samples as they were being pulled apart.

Sample #	Average load (kgf)					
	Ethanol			Isopropanol		
	Solvent	Heat	Vapour	Solvent	Heat	Vapour
1	0.181	0.022	0.058	0.154	0.024	0.043
2	0.310	0.021	0.045	0.200	0.022	0.031
3	0.134	0.022	0.031	0.236	0.020	0.026
4	0.141	0.021		0.241	0.024	0.024
5	0.237	0.025	0.027	0.157	0.030	-0.006
6	0.238	0.020	0.043	0.213	0.022	-0.012
7	0.247	0.020	0.060	0.171	0.022	-0.009
8	0.169	0.020	0.100	0.175	0.026	-0.005
9	0.181	0.020	0.084	0.241	0.027	0.037
10	0.212	0.019			0.025	
Coefficient of variation	26.477	7.889	45.498	18.061	11.125	150.855
Maximum	0.310	0.025	0.100	0.241	0.030	0.043
Mean	0.205	0.021	0.056	0.199	0.024	0.014
Median	0.197	0.021	0.051	0.200	0.024	0.024
Minimum	0.134	0.019	0.027	0.154	0.020	-0.012
Range	0.176	0.005	0.073	0.087	0.009	0.055
Standard deviation	0.05429	0.00165	0.02544	0.03585	0.0027	0.02181

Key	
cohesive failure of the substrate	
adhesive failure	
adhesive and substrate failure	

Table 2: Average load for the T-Peel test

One ethanol vapour reactivated sample was not tested because the adhesive failed before it could be loaded in the tensile testing machine. Sample 4 does not have an average load because the adhesive failed around halfway through being pulled apart.

Sample 10 of the isopropanol solvent does not have a value because the sample tore immediately and the data would have been just like the rest from that sample set. Sample 10 of the isopropanol vapour reactivation does not have an average load because the adhesive

failed around halfway through being pulled apart. Some of the average loads are negative due to the adhesive being partially detached before the sample was loaded and this data was not factored into the graphs.

The two following figures serve as comparisons between the two different adhesive mixtures, Klucel G in ethanol and Klucel G in isopropanol, and a comparison between the three different methods of reactivation.

Figure 8 shows the average of the maximum force results for all the T-Peel tests.

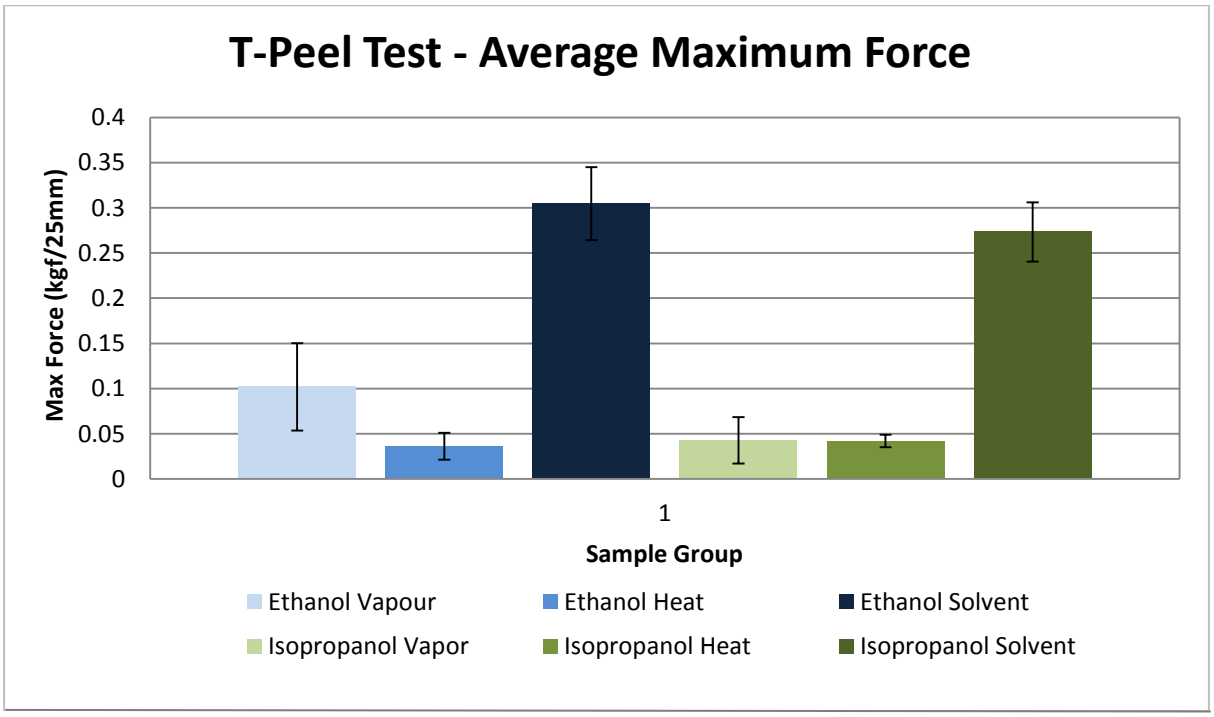

Fig. 8: T-Peel Test- Average Maximum Force

Figure 9 shows the mean of the average force exerted on the samples as they were being pulled apart. To clarify, the tensile tester collected the force it took to peel the sample apart all along the length of the sample, which gave the average force for each sample. The mean of the samples' average forces is shown below.

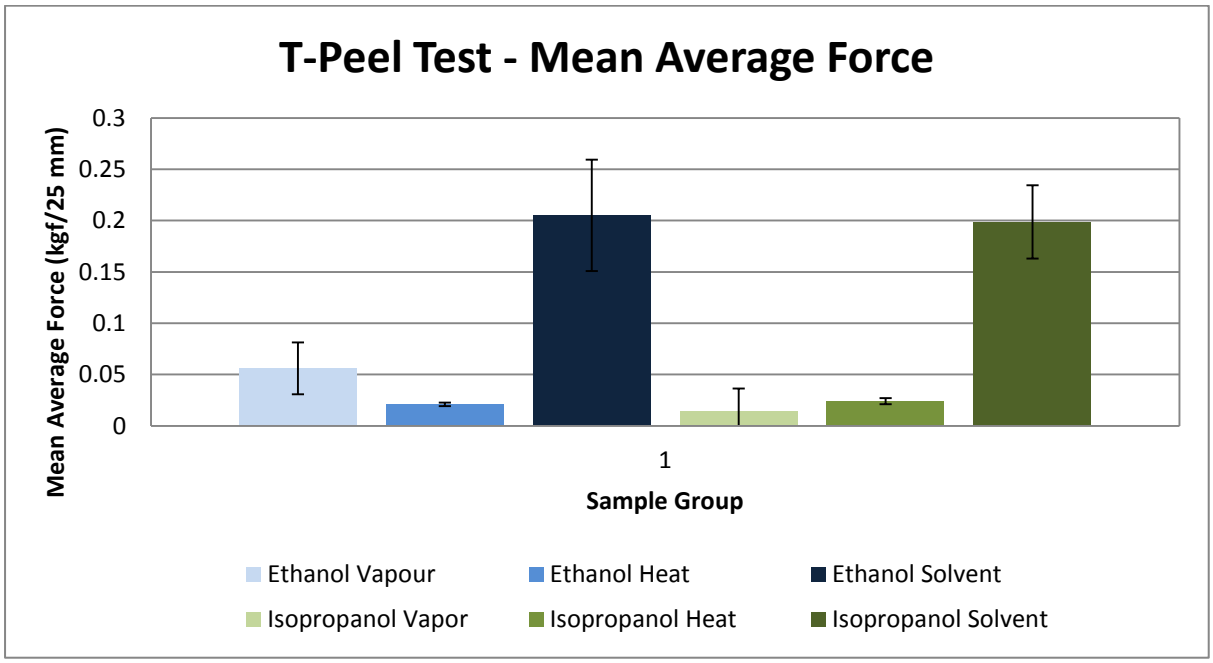

Fig. 9: T-Peel Test- Mean Average Force

4.4 MICROSCOPIC ANALYSIS

The following photomicrographs in figure 10 show cross sections of the dyed adhesive penetration into the tissue for the two adhesives and the three methods of reactivation. The dark portion on the right side of three of the images is just a shadow that occurred during photography.

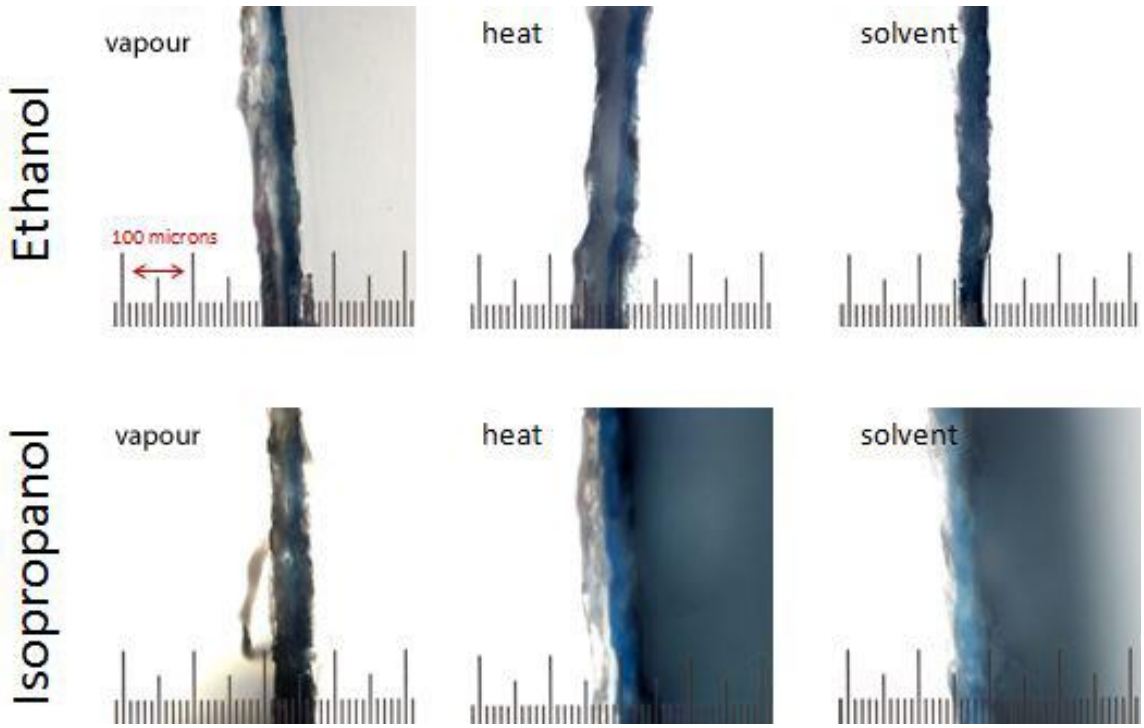

Fig. 10: Photomicrographs of dyed adhesive sample cross sections

For both adhesive types, the solvent reactivation caused the deepest penetration at close to 100%. The heat and vapour reactivation did not cause a very deep penetration into the tissue which could explain why those samples performed poorly in the tensile testing.

Comparing the reactivation using ethanol or isopropanol showed that the isopropanol reactivation caused a slightly deeper penetration of the adhesive into the tissue.

5. DISCUSSION

5.1 ADHESIVE

Two adhesive solutions were prepared according to the procedure explained in the Experimental section. It was hypothesized that the Klucel G in isopropanol would have the strongest adhesion and that the direct application of the solvent would reactivate the adhesive more fully to make the stronger bond. Since isopropanol is less volatile than ethanol the adhesive would have more time to penetrate the tissue before drying. This diffusion of the adhesive would provide a better bond to the tissue and would therefore make a stronger mend.

There was no correlation between the type of solvent used to prepare the adhesive and the strength of the bond. This was demonstrated by the consistency of the heat reactivated samples being weak. Since neither solvent was used to reactivate the adhesive and the heat reactivation results were so consistent, it was determined that the solvent used to make the adhesive did not affect the strength of the bond. This was understandable since all of the solvent used to make the adhesive would have evaporated off before the adhesive was reactivated to make the sample.

5.2 SOLVENT USED FOR REACTIVATION

The results of the LJSS and T-Peel tests did not show that ethanol or isopropanol made the stronger mend. However, when those results were compared with that of the substrate tensile strength, it was determined that the isopropanol reactivation made the strongest bond. All of the solvent reactivated samples failed within the substrate, so those values should reflect that of the tensile strength of the substrate. This was the case in the isopropanol samples when the variance was calculated to give the p-values. The p-value when comparing the LJSS of the substrate and the LJSS of the isopropanol sample was 0.2739. This meant that the results were very similar. When the LJSS of the substrate was compared to the LJSS of the ethanol sample, the p-value was 0.0088. This value was much lower because there was a greater variance in the two sets of data. The substrate was stronger than the ethanol reactivated samples. Therefore, the isopropanol reactivation caused the stronger bond.

The microscopy results indicated the reactivation with isopropanol allowed the adhesive to penetrate deeper into the tissue than the reactivation with ethanol, both with the direct application of the solvent with a brush and the solvent vapour. This was consistent with the tensile testing results that isopropanol made the strongest bond.

5.3 REACTIVATION METHOD

It was hypothesized that the direct application of the solvent with a brush to the adhesive would make the stronger mend. The solvent would solubilize the adhesive more thoroughly than solvent vapour or heat and would therefore drive the adhesive further into the tissue to make a stronger bond with the fibres.

The results of the tensile testing did support the hypothesis. The solvent reactivated samples were consistently stronger than the other methods of reactivation with both tensile tests and both ways of preparing the adhesive. During the LJSS and T-Peel tests, the samples that were reactivated with the brushed on solvent consistently broke or tore within the substrate, so the strength of the adhesive bond is still unknown. All that could be determined was that the adhesive was stronger than the tissue. These results were supported by the microscopic analysis because the adhesive penetrated into the tissue the deepest in the samples reactivated with the brush applied solvent.

The next strongest reactivation method was more difficult to determine. Both of the tensile tests show that the vapour and heat reactivation were weaker than the solvent reactivation. The microscopy results show that the adhesive did not penetrate very far with heat or vapour reactivation with either of the adhesives.

6. CONCLUSIONS

- There was no correlation between the type of solvent used to prepare the adhesive and the strength of the bond.
- The reactivation with isopropanol allowed the adhesive to penetrate further into the tissue than the reactivation with ethanol, both with the brush applied solvent and the solvent vapour.
- The solvent reactivated samples were consistently stronger than the other methods of reactivation with both tensile testing methods and both methods of preparing the adhesive.
- Further testing could be done to determine if these methods of reactivation are still viable options. The heat reactivation could be attempted at higher temperatures or be left on the sample longer to reactivate the adhesive more fully. The vapour reactivation could be tested by leaving the samples in the vapour chamber longer to determine if the adhesive could be reactivated more fully.

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