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# Aquazol-Coated Remoistenable Mending Tissues

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## Abstract

A study was performed to evaluate the suitability of Aquazol as an adhesive for preparing remoistenable mending tissues to treat paper-based collections. Aquazol [poly (2-ethyl-2-oxazoline)] is a non-toxic, synthetic, water-soluble adhesive; it was studied because of its good adhesion strength, good retention of flexibility, and excellent reversibility. Various formulations of Aquazol-coated remoistenable tissues were prepared, using two molecular weights of Aquazol (50 and 200), in 10% and 15% weight/volume solutions, with water and alcohol as solvents. The sample remoistenable tissues were used to mend tears on historic handmade paper, newsprint, and clay-coated paper. Mended paper samples were assessed to compare adhesion strength, reversibility, and response to humid conditions. In successful formulations, reactivation of the adhesive layer occurred quickly, with very minimal water or alcohol, resulting in a suitably tacky mending tissue; upon drying the adhesion strength was comparable to that of wheat starch paste. Because so little moisture or solvent is required to reactivate the adhesive layer, Aquazol-coated mending tissues are suitable for treating water-sensitive media, coated papers, and papers prone to tide line formation.

## Titre et Résumé

### Papiers de soie réhumectables enduits d'Aquazol

Une étude a été réalisée afin d'évaluer la pertinence d'utiliser l'Aquazol comme adhésif dans la préparation de papiers de soie réhumectables servant à traiter des objets de collections à base de papier. L'Aquazol [la poly(2-éthyl-2-oxazoline)] est un adhésif synthétique hydrosoluble non toxique dont l'étude a été entreprise en raison de sa bonne force d'adhérence, du maintien satisfaisant de sa souplesse et de son excellente réversibilité. Diverses formulations de papiers de soie réhumectables enduits d'Aquazol ont été préparées, en utilisant deux produits de poids moléculaires distincts (Aquazol 50 et Aquazol 200), dans des solutions à 10 % et à 15 % (poids/volume), avec de l'eau et de l'alcool comme solvants. Les échantillons de papiers de soie réhumectables ont été utilisés pour réparer des déchirures présentes sur du papier couché au kaolin, du papier journal et du papier fait à la main de nature historique. L'état des échantillons de papiers traités a été évalué afin de comparer la force d'adhérence, la réversibilité et le comportement dans des conditions humides. Les résultats obtenus avec certaines formulations sont encourageants : la réactivation de la couche d'adhésif est rapide, pour une teneur minimale en eau ou en alcool, ce qui produit un papier de soie de réparation poisseux adéquat; en outre, une fois le produit séché, la force d'adhérence est comparable à celle de la colle d'amidon de blé. Comme la quantité d'humidité ou de solvant requise pour la réactivation de la couche d'adhésif est si faible, les papiers de soie enduits d'Aquazol constituent un matériau adéquat pour traiter les médiums sensibles à l'eau, les papiers couchés et ceux sur lesquels des auréoles peuvent facilement se former.

## Introduction

Book and paper conservators traditionally favor adhesives that require water for their preparation and utilization. When using adhesives such as wheat starch paste to treat water-sensitive materials, the amount of moisture needed to achieve adequate adhesion may damage sensitive media or cause tide lines. In response to this challenge, remoistenable-mending tissues—long-fiber tissue coated with aqueous or solvent-based adhesive mixtures that require minimal water or solvent to reactivate—have been developed and used successfully to treat moisture-sensitive materials. While Aquazol does not appear to be well known among book and paper conservators, a prior study involving Aquazol as an adhesive for textile conservation treatments revealed that it exhibits good adhesion strength and flexibility, is readily reversible, and might also be useful for book and paper conservation (Lechuga 2009). In addition, remoistenable tissues were found to be more easily and quickly prepared with Aquazol than with other adhesives. This paper reports on a study conducted to evaluate the suitability of Aquazol-coated-remoistenable-mending tissues for the treatment of paper objects.

Remoistenable tissues prepared with various proportions of wheat starch paste and methyl cellulose (Baker 1990; Brückle 1996; Wagner 1996) and acrylic-based adhesives such as Lascaux 498HV and Lascaux 360HV (Anderson 2003) have been successfully used to treat moisture-sensitive paper-based artifacts. Reporting on a survey of conservators' use of pre-coated-mending tissues, Anderson and Reidell (2009) concluded that book and paper conservators are familiar with remoistenable-mending tissues and they support their use when treating water-sensitive materials. Respondents to their survey most commonly used starch adhesives, cellulose ethers, protein adhesives, and acrylic-based polymers to prepare such tissues. In a comprehensive study of adhesives used for creating remoistenable-mending tissues, Pataki (2009) highlighted additional adhesives such as gelatin, isinglass, and Aquazol as potential choices for book and paper conservation treatments.

Aquazol, poly (2-ethyl-2-oxazoline), is a synthetic, water-soluble polymer (see Figure 1). The polymer's physical and chemical characteristics, and its suitability as an adhesive for treating cultural artifacts, have received some attention in the conservation literature. Paintings and objects conservators have successfully used Aquazol in a variety of contexts, including as a consolidant, as an inpainting medium, and as an adhesive for gilding preparations (Arslanoglu 2003; 2004; 2005; Shelton 1996; Wolbers 1998). Arslanoglu (2005, p. 107) noted that the presence of polar and non-polar regions facilitates Aquazol's interaction with a wide range of solvents and allows it to adhere to various types of surfaces. Wolbers' (1998) investigation of Aquazol's characteristics, in which samples of Aquazol 50 and Aquazol 500 were artificially aged for the equivalent of approximately 24 years, concluded that the polymer did not discolor significantly, its pH remained virtually unchanged, and it tended more toward chain scission than cross-linking. Studies of Aquazol's use as an inpainting medium and consolidant for paintings conservation treatments (Arslanoglu 2003; 2004; 2005) confirmed that Aquazol films retain good flexibility and do not shrink considerably upon drying, as compared with other commonly used adhesives such as gelatin and sturgeon glue. Arslanoglu (2003, p. 14; 2005, p. 108) further observed that during moisture uptake, Aquazol films took longer to reach equilibrium and absorbed more moisture by weight than other adhesives studied. Despite Aquazol's hygroscopicity, interviews conducted by Arslanoglu (2005, p. 110) confirmed

conservators' satisfaction with Aquazol treatments over time, with none having observed humidity-induced treatment failures.

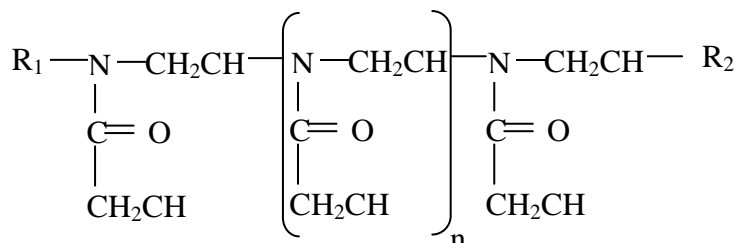


Figure 1. Chemical structure of Aquazol, poly (2-ethyl-2-oxazoline).

In previous research, the author explored Aquazol's thermoplastic characteristics to assess its suitability as a heat-set adhesive for consolidating shattered, silk textiles. Results were promising; heat-set fabrics prepared with Aquazol were successfully applied to shattered silk using minimal heat and retained excellent flexibility upon cooling (Lechuga 2009). Other favorable characteristics of Aquazol included its solubility in a variety of solvents, strong adhesion in relatively low concentrations, and excellent reversibility. Treatment concerns included Aquazol's sensitivity to high humidity and its tendency to remain slightly tacky in ambient conditions. While prepared Aquazol-coated-heat-set fabrics were found to be slightly tacky at room temperature, once reactivated with heat they were no longer tacky. However, in areas of loss to the damaged textile, where the heat-set fabric remained exposed and the adhesive had not been reactivated, clearing—i.e., the removal of unwanted excess adhesive—was necessary and accomplished by rolling a water-dampened swab across the exposed area. Aquazol's sensitivity to humid conditions was observed as moderate staining on silk stabilized with Aquazol-coated fabric when exposed to humidity levels of approximately 75% RH for several weeks. Staining was removed in a brief bath of deionized water.

## Methods

To evaluate the suitability of Aquazol-coated-remoistenable-mending tissues for the treatment of paper objects, 28 formulations of Aquazol-coated tissues were prepared and used to perform test mends on historic handmade paper, newsprint, and clay-coated paper. Mends were subjected to aggressive handling<sup>1</sup> and elevated humidity conditions in order to assess their efficacy. The reversibility of mends was also evaluated.

### Aquazol-coated tissue preparation

Book and paper conservators tend to use thin, long-fibered tissues for mending paper to achieve strong, flexible, and visually unobtrusive repairs. Therefore, this study employed four lightweight 100% kozo fiber papers—usu-mino, usu-mino thin, tengucho, and tengucho thin—procured from Hiromi Paper, Inc.

Seven solutions of Aquazol were studied (see Table 1). Deionized water, ethanol, and isopropyl alcohol were selected to prepare the adhesive solutions because they are commonly used by book and paper conservators, they pose minimal risk to both the artifact and conservator, they

are widely available, and they are easily disposed of. Aquazol is available in three molecular weights of increasing polymer chain size and adhesion strength: 50, 200, and 500. Based on the results of previous research conducted by the author and on the results of pretests in which a selection of Aquazol-coated tissues were used to mend paper, a 10% solution of Aquazol 50 weight/volume (w/v) was initially selected for the study. This concentration appeared to possess sufficient adhesion strength characteristics for paper mending; however, tengucho thin tissues coated with the 10% solution of Aquazol 50 consistently failed to perform well. The author hypothesized that the reactivation solvent forced the adhesive through the thin paper onto the support below where it accumulated. In an attempt to address this problem, aqueous solutions of 15% Aquazol 50 and 10% Aquazol 200 were also studied. Water was used as the solvent for these two additional solutions because its strong surface tension minimized adhesive penetration within the paper fibers, thereby improving adhesive film formation.

Table 1. Aquazol Solutions Tested

10% Aquazol 50 in:
• water
• ethanol
• isopropyl alcohol
• water:ethanol (1:1)
• water:ethanol (9:1)
15% Aquazol 50 in:
• water
10% Aquazol 200 in:
• water

Adhesive solutions were prepared by mixing appropriate amounts of Aquazol granules and solvent in a beaker. The beaker was covered and the mixture was occasionally stirred until all of the solids dissolved; solutions were ready to use within a few hours. Prepared solutions were slightly viscous and exhibited a pale yellow cast, with solutions of Aquazol 50 appearing slightly more yellow than the Aquazol 200 solution.

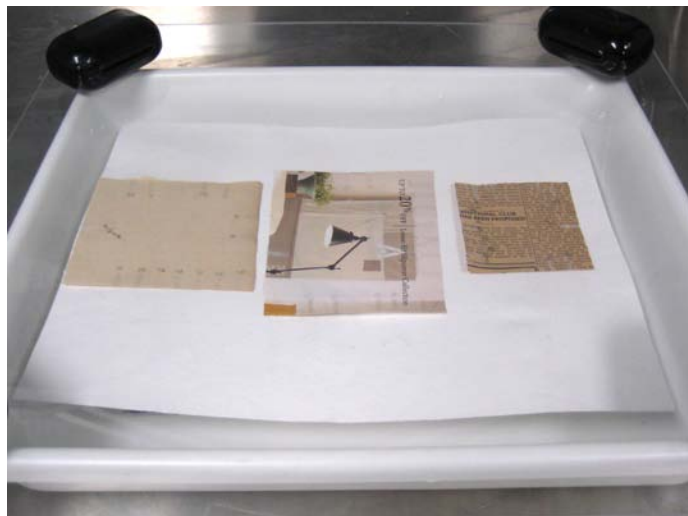
Applying the seven adhesive solutions to the four kozo-fiber papers produced 28 variations of Aquazol-coated-remoistenable tissues. Samples were prepared by placing a piece of tissue on a sheet of smooth silicone-release polyester and brushing the Aquazol solution onto the tissue, fully and evenly saturating it; the tissue was then air dried. A second coating of adhesive solution was applied to all samples prepared with usu-mino papers as one coating did not produce a satisfactory adhesive film.

### Performing test mends

Pretesting revealed that the solvent used to reactivate the adhesive impacted the working time and ultimate successfulness of the mends. Several tissue samples were reactivated with deionized water, ethanol, and isopropyl alcohol. Tissues reactivated with deionized water exhibited the longest working time; ethanol tended to evaporate too rapidly, but isopropyl alcohol was found to be a successful alternative due to its slower evaporation rate (Horie 1987, p. 189). It was observed that tissues reactivated with water retained better adhesion strength; therefore deionized water was used to reactivate all test mends performed in this study.

Employing the 28 sample remoistenable tissues to mend tears on three types of paper—historic handmade paper, newsprint, and clay-coated paper—resulted in 84 test mends. To perform each test mend, a small strip of tissue was lightly dampened with water on a polyester support, which extended working time, positioned over the tear, boned down, and allowed to dry under a blotter and weight. Test mends were then subjected to aggressive handling to assess their strength. Mends were deemed unsuccessful if at least half of the mending strip lost its adhesion to the paper substrate. Reversibility of successful mends was attempted by applying minimal amounts of water, ethanol, and isopropyl alcohol to the mends and immediately attempting removal.

To evaluate the mends' response to humid conditions, additional mended samples of all three paper types were placed in a passive humidity chamber buffered to approximately 75% RH using a saturated sodium chloride solution, as specified by Padfield (2011) (see Figure 2). As a baseline for comparison, a mend of remoistenable-tissue prepared with methyl cellulose and wheat starch paste was also adhered to the three paper samples. The mended papers remained in the chamber for approximately 30 hours. Upon removal, the samples were aggressively handled and if at least half of a mending strip lost its adhesion to the paper substrate, the mend was deemed to have failed. Finally, to evaluate the polymer's behavior in extremely damp conditions, the samples were placed in a Gore-Tex<sup>2</sup> damp pack for 15 minutes.



*Figure 2. Passive humidity chamber with mended samples of handmade paper, clay-coated paper, and newsprint.*

## Results

The results of this study have been summarized in Table 2. During mending, the Aquazol film on the sample remoistenable tissues, was quickly reactivated with a swab or brush lightly dampened with water. In general, the amount of water required to reactivate the adhesive was slightly less than that used when reactivating remoistenable tissues prepared with wheat starch paste and methyl cellulose. It was observed that the amount of moisture used to reactivate the adhesive impacted the ultimate success of the mends. If too much water was applied, mends were prone to failure, especially when using thinner tissues. Excessive moisture appeared to cause the Aquazol layer to re-solubilize and penetrate through the tissue fibers, resulting in the

adhesive accumulating on the polyester support below, rendering the mending tissue ineffective. During reactivation, only enough moisture should be employed so that the adhesive becomes tacky but not wet. The Aquazol 200 adhesive layer seemed to penetrate tissue fibers less than the Aquazol 50 adhesive film, presumably due to the polymer's increased molecular weight.

In this study, the remoistenable tissue samples that performed best were those prepared with aqueous solutions of Aquazol and those prepared using tengucho paper. Usu-mino papers performed well only when coated twice with aqueous solutions of Aquazol. Tissues coated with alcohol preparations of Aquazol were more transparent than those coated with aqueous preparations, presumably due to increased paper fiber penetration by the adhesive. Generally, Aquazol-coated tissues adhered best to newsprint and clay-coated paper, but frequently failed when adhered to handmade paper.

Exposure to elevated humidity levels of approximately 75% RH for 30 hours in a passive humidity chamber caused some of the successful mends to fail (i.e., at least half of the mending strip lost its adhesion to the paper substrate following passive humidification and aggressive handling); however, none of the successful mends became fully detached under these conditions. Tissue samples adhered to handmade paper exhibited the highest level of humidity-induced failure with six of the 15 mends becoming detached, while four of the 15 mends adhered to both newsprint and clay-coated paper failed. In contrast, passive humidification caused the remoistenable tissue prepared with methyl cellulose and wheat starch paste to fail on all three paper substrates. Tissues coated with 10% Aquazol 200 fared best following humidification, with two of the 12 samples having failed, followed by the aqueous preparation of 10% Aquazol 50, with two out of nine samples becoming detached.

Table 2. Results

Adhesive	Solvent	Tissue type			
		Tengucho thin	Tengucho	Usu-mino thin*	Usu-mino*
<b>Mends adhered to handmade paper</b>					
10% Aquazol 50	water		✓	✓	✓
	ethanol		✓		
	isopropyl alcohol		✓		
	water: ethanol (1:1)		✓		
	water: ethanol (9:1)		✓		
15% Aquazol 50	water	✓	✓	✓	✓
10% Aquazol 200	water	✓	✓	✓	✓
<b>Mends adhered to newsprint</b>					
10% Aquazol 50	water		✓	✓	✓
	ethanol		✓		
	isopropyl alcohol		✓		

	water: ethanol (1:1)		✓	
	water: ethanol (9:1)		✓	
15% Aquazol 50	water	✓	✓	✓ ✓
10% Aquazol 200	water	✓	✓	✓ ✓

**Mends adhered to clay coated paper**

10% Aquazol 50	water		✓	✓	✓
	ethanol		✓		
	isopropyl alcohol		✓		
	water: ethanol (1:1)		✓		
	water: ethanol (9:1)		✓		
15% Aquazol 50	water	✓	✓	✓ ✓	
10% Aquazol 200	water	✓	✓	✓ ✓	

- Unsuccessful mend (i.e., did not withstand aggressive handling)
- ✓ - Mend failed after passive humidification (75% RH for 30 hours) and manipulation
- ✓ - Successful mend (i.e., tissue retained good adhesion after humidification and manipulation)

\* Two coats of Aquazol solution were used to prepare the usu-mino and usu-mino thin remoistenable tissue samples

**Reversibility**

All sample mends were successfully reversed using minimal amounts of deionized water, ethanol, or isopropyl alcohol; however, if excess solvent was employed during reversal, staining would occur, especially on newsprint and handmade paper samples, presumably from the solvated adhesive penetrating the paper substrate. This phenomenon appears to be somewhat related to the molecular weight of Aquazol resins. This characteristic was previously observed when reactivating thinner tissues coated with 10% Aquazol 50 wherein the adhesive solution penetrated through the paper fibers, failing to leave an adequate adhesive film on the tissue. As with the tissue preparations, the higher molecular weight 10% Aquazol 200 solution did not appear to penetrate as much as Aquazol 50 preparations, resulting in less staining (see Figure 3).

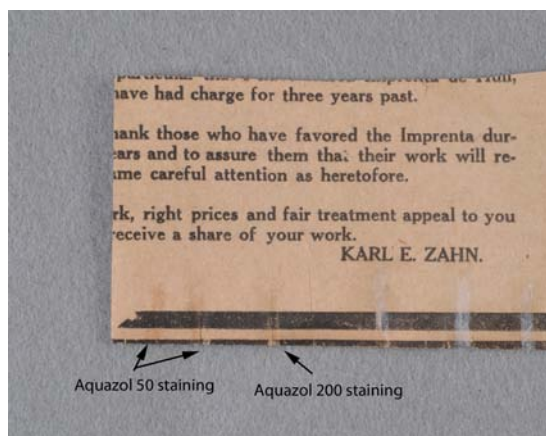


Figure 3. Detail of relative staining resulting from different molecular weights of Aquazol. Aquazol 50, which penetrated the newsprint more than Aquazol 200, resulted in a darker stain.

Because Aquazol is soluble in water and alcohols, should staining occur it is readily reversed, assuming the media can handle the remedy, by rolling a swab lightly dampened with an appropriate solvent repeatedly over the surface (see Figure 4), or by applying water or solvent to the affected area on a suction platen or table. If treatment reversal becomes necessary, minimal amounts of moisture or solvent should be used to prevent staining.

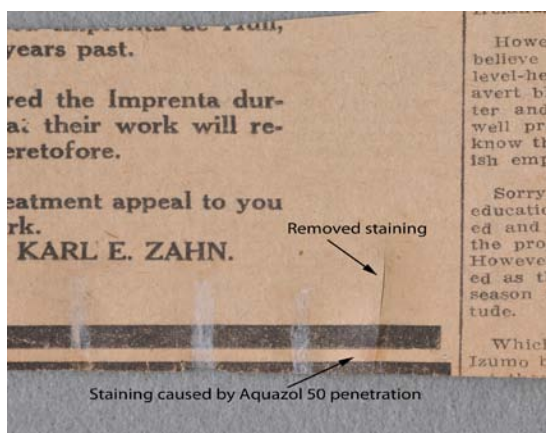


Figure 4. Detail following removal of stains caused by Aquazol 50 penetration.

Similar staining was observed when samples were exposed to the extremely humid conditions of a Gore-Tex damp pack for 15 minutes. All mends failed on all three paper substrates and staining was observed only on the handmade paper and newsprint samples; however, staining was minor, and was readily reversed using the methods described above.

## Discussion

The results of this study indicate that Aquazol is well suited to the preparation of remoistenable-mending tissues for treating paper-based artifacts. With minimal setup and materials, a thin layer of Aquazol adhesive can be easily applied to long-fibered papers by directly brushing the adhesive solution onto tissues. During drying, the adhesive accumulates on the bottom side of the tissue, against the plastic, producing an even, thin adhesive film. This method is akin to the preparation of heat-set fabrics for textile conservation, wherein an adhesive solution is brushed directly onto a carrier fabric and allowed to dry (CCI 1999).

Aquazol's solubility in a variety of solvents allows adhesive films to be reactivated with solvents other than those used for tissue preparation, enabling one to tailor tissues to individual circumstances. It was observed that the solvent used to prepare the Aquazol solution impacted the visual characteristics of the resulting remoistenable tissues. Tissues coated with alcohol solutions resulted in relatively transparent mends, whereas those prepared with deionized water retained more of the tissue's original opacity. The lower surface tension of alcohol solutions allows the adhesive to penetrate the paper fibers more than those prepared with water, presumably causing a change in refractive index that resulted in more transparent mends. Care should be taken to avoid employing too much water or solvent when applying or removing mends as Aquazol readily penetrates porous materials. While penetration of a porous substrate is advantageous when consolidating friable paint, it may be undesirable when treating paper-based artifacts as it can lead to staining especially on uncoated papers. In this study, Aquazol 50 solutions were found to be more prone to excess penetration and staining than Aquazol 200 solutions; stains were removed by rolling a damp swab over the affected area or by applying an appropriate solvent to the stain on a suction platen.

The results of this study indicate that tissue thickness can also influence the success of Aquazol-coated-remoistenable tissues. When coated with a 10% solution of Aquazol 50, *tengucho* thin—the thinnest of the tissues studied—adhered poorly to all three paper types. *Tengucho* thin tissue performed well once coated with aqueous solutions of 15% Aquazol 50 and 10% Aquazol 200. The greater concentration of Aquazol 50 and the higher molecular weight of Aquazol 200, combined with the strong surface tension of water, minimized adhesive penetration and improved film formation upon drying. During reactivation, this thicker adhesive film may have retained moisture longer, thereby increasing the likelihood of achieving good adhesion. The thicker *usu-mino* papers readily absorbed the adhesive solutions and a satisfactory adhesive film could only be achieved by applying a second coat of aqueous Aquazol solution, allowing the adhesive to dry between applications.

Despite the hygroscopic nature of Aquazol, testing in a humid environment revealed that most tissue samples retained good adhesion on smooth surfaced papers, but demonstrated a higher incidence of failure when adhered to handmade paper. No staining of paper substrates was observed after passive humidification, however samples placed in the Gore-Tex damp pack did produce staining only on the handmade paper and newsprint. This characteristic allows for treatment reversal using closely monitored passive humidification instead of more aggressive techniques, reducing the potential for staining.

## Conclusion

The results of this research indicate that Aquazol may hold promise for some book and paper conservation applications. Aquazol-coated-remoistenable tissues may be easily and quickly prepared with equipment commonly found in the conservation laboratory; and because the polymer can be dissolved, reactivated, and reversed in a variety of solvents, the working properties and visual characteristics of Aquazol-coated tissues may be adjusted to suit individual circumstances. While Aquazol exhibits sensitivity to humid conditions, exposure to moderately high humidity (approximately 75% RH) did not cause many mends to fail. Upon exposure to extremely damp conditions (approximately 90%-95% RH) all mends failed and some staining occurred. Aquazol-coated tissues adhered best to newsprint and clay-coated paper, while less well to handmade paper, indicating that they may be more appropriate for treating smooth-surfaced papers. In addition to using Aquazol-coated-remoistenable tissues for mending tears in paper, they could be used as bridge mends, or as hinges for mounting artwork for short-term exhibits. Further testing, long-term aging, and case studies need to be conducted to assess the polymer's stability and performance in actual collections storage environments over time and to ensure that items treated with Aquazol-coated tissues can withstand the demands of repeated use.

## Acknowledgements

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## Endnotes

1. "Aggressive handling" was conducted by attempting to peel apart the mend by pulling the paper in opposing directions on either side of the mend. The mended area was then curled at least three times to determine if the mend would fail during flexing.
2. A Gore-Tex damp pack is constructed by placing two sheets of Gore-Tex, smooth sides together, on top of damp blotters. Additional damp blotters are placed onto the topmost layer of Gore-Tex then the entire "sandwich" is covered with polyester sheeting to minimize moisture loss. The object to be humidified is placed between the smooth sides of the Gore-Tex sheets. This method of humidification is rather aggressive as humidity levels are typically very high (approximately 90%-95% RH) within the damp pack.

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## Materials and Suppliers

*Aquazol 50 and Aquazol 200 polymers*

Talas

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