Article: Nanocellulose Application in Photograph Conservation
Author: Marissa Maynard
Source: Book and Paper Group Annual 42, 2023
Pages: 1-10
Editors: Roger S. Williams, Managing Editor, and Amy Crist, Assistant Editor
Editorial Office: bpgannual@gmail.com
ISSN: 2835-7418

MARISSA MAYNARD

Nanocellulose Application in Photograph Conservation

INTRODUCTION

In recent years, there has been a surge of research in the application of nanocellulose in multiple disciplines including material science, biomedical engineering, and art conservation, to name a few. Nanocellulose is "cellulosic extracts or processed materials having defined nano-scale structural dimensions" (Abitbol et al. 2016, 76). There are three main types of nanocellulose: cellulose nanocrystals (CNCs), also known as nanocrystalline cellulose (NCC); cellulose nanofibrils (CNFs); and bacterial cellulose (BC). A variety of methods is used to extract the nanoparticles from the different sources, and each method results in varied crystallinities, surface chemistries, and mechanical properties, all which can be utilized for different applications (Abitbol et al. 2016, 76). For instance, CNFs are ultimately entangled fibrils that are composed of both amorphous and crystalline cellulose components, unlike CNCs which are almost perfectly crystalline (~90%). There are three main processes to create CNFs: mechanical treatments, chemical treatments, and a combination of both. Unlike the other two types of nanocellulose, BC is synthesized as pure cellulose; therefore, lignin and hemicellulose do not need to be removed (Völkel et al. 2017). This distinction is of particular importance to paper conservators, as lignin and hemicellulose can be the source of deterioration in paper-based objects made from poor-quality paper.

One of the important properties of nanocellulose to consider is its tensile strength, which varies among the different types of nanocellulose. This characteristic is of some interest to paper conservators especially in tear repair. Furthermore, nanocellulose displays many optical characteristics that are also useful for paper conservation. CNCs and CNFs can be cast as optically transparent films which are useful for tear repair of thin objects. A study conducted at the National Library in France demonstrated that nanocellulose film combined with 5% Klucel G in ethanol worked very well when repairing tears on translucent paper objects (Dreyfuss-Deseigne 2017, 36).

Papers presented during the Book and Paper Group Session, AIC's 51st Annual Meeting, May 16–20, 2023

Another study tested the hypothesis that, due to the compatibility between nanocellulose and paper-based artworks, the addition of an adhesive is unnecessary when applying nanocellulose as a mending material (Völkel et al. 2017). The authors tested several types of nanocellulose suspensions that were modified with ethanol and gelatin. The suspensions, under a vacuum to control moisture, were brushed on or applied with a film applicator to different test papers, including rag paper, book paper, paper with lignin, and Whatman paper. They were then dried for 12 hours. Once the samples were prepared, they were analyzed using microscopy, the tensile strength was measured, and brightness and visual characteristics were observed. The samples were then aged and tested again. Overall, the authors found it possible to modify the nanocellulose suspensions by adjusting the water content during preparation and adding adhesives like gelatin in different concentrations. However, these modifications changed some properties of the nanocellulose, including surface sheen, tack, and fiber length. The higher the concentration of nanocellulose, the hazier the appearance of the film. BC appears shinier, whereas CNF films appear more matte, with a whitish haze. In general, the modified nanocellulose suspensions aged well and did not cause damage to the paper substrate, thus demonstrating a promising method for tear repairs or other treatment options in paper conservation.

Another common treatment in paper conservation that has benefited from the addition of nanocellulose is the calcium phytate treatment to stabilize paper with iron gall ink degradation. A more recent study by Völkel et al. (2020) incorporated nanocellulose into different steps of the standard calcium phytate process and then aged the samples to determine if they had visually, chemically, and mechanically changed. They also used LA-ICP-MS to track the movement of iron migration in the paper substrates, as that is one of the main concerns when treating objects with iron gall ink. The authors found that the addition of the nanocellulose fibers did not impair chemical treatment and provided significant physical stabilization during the process. This study added to the body of research demonstrating the usefulness of modified nanocellulose in paper conservation treatments, such as

Trial	Solution	Colorant	Number of Sheets	Thickness
1	100% water	Pan watercolor: dark gray/black	4	0.0095 mm
2	100% water	Pan watercolor: light dark	4	0.0095 mm
3	50/50 water and ethanol	Tube watercolor: gray	3	0.0095 mm
4	90% water and 10% ethanol	QOR watercolor: dark gray with pearl	3	0.0095 mm
5	85% water and 15% ethanol	QOR watercolor: warm brown/yellow	3	0.0095 mm
6	Water and retention agent	Aardvark colors	3	0.0105 mm
7	Water and less retention agent	Aardvark colors	3	0.0105 mm
8	Water and retention agent	Aardvark colors	3	0.0105 mm
9	Water, ethanol, and 2.5% methyl cellulose	QOR watercolors	3	0.0095 mm
10	Water, ethanol, and 5% methyl cellulose	QOR watercolors	3	0.0095 mm
Control	Water	No pigment	3	0.0095 mm

Table 1. Summary of the Components for the Different Colorant Trials

utilizing gelatine-infused nanocellulose in the treatment of paper damaged by copper-based pigments or iron gall ink.

Finally, Canham, Murray and Hill (2023) published on the practical aspects of nanocellulose, as well as its use as a remoistenable or precoated tissue substrate. The authors conducted several tests to characterize the shrinkage and expansion of nanocellulose when moisture is introduced to the nanocellulose film. They also tested several adhesives that are commonly used to create remoistenable tissue, including methyl cellulose, a mixture of methyl cellulose and wheat starch paste, Klucel G, gelatin, and Aquazol 200. The authors found potential for remoistenable tissues prepared with methyl cellulose and gelatin with the addition of nanocellulose.

The research presented here builds on the preceding studies and demonstrates how nanocellulose can be used to create colored fills with different surface textures and glosses that can then be applied to fills on photographs. Matching fill materials with the original photographs can be difficult due to the varied surface glosses and tonal ranges possible in photographs. Nanocellulose presents a unique opportunity to help solve this difficulty because the nanocellulose pulp can be colored and cast before it is applied to the photograph. The goal of this study is to find the best way to color, cast, and apply fills to different types of photographs. This was accomplished through a variety of trials using different coloring agents including watercolors, Aardvark colors, and acrylic paints. These colorants were mixed with the nanocellulose suspension in combination with water and ethanol. The films were then applied to photographs using common adhesives used in conservation, including wheat starch paste, gelatin, Klucel G, and methyl cellulose. Overall, the best results were obtained with QOR watercolors sized with methyl cellulose and then applied to the photograph with methyl cellulose; however, several interesting observations were also made throughout the trials, including a difference in gloss and color between the mold side and air side of the nanocellulose films.

EXPERIMENTS

To determine what materials and methods allowed for the best coloration of the nanocellulose, several different colorants were tried, including tube watercolors, pan watercolors, Aardvark colors, QOR watercolors, and acrylic paints. Table 1 shows the different variables tested in the trials. Step-by-step procedures for each trial type are presented in the appendix.

Although different colorants were used to color the film, the general procedure remained the same. First, a small amount of nanocellulose was weighed. The amount depended on how many sheets were to be made, the desired thickness of the films, and the diameters of the molds used to cast the films. All of this data was input into an online calculator designed by Canham and Yeomans to determine the proper amount of nanocellulose needed (http://www.burroakbookbinding.com/nanocellulose-calculator/). Then half the amount of water was added to the nanocellulose along with a stir bar. This was stirred for a few minutes using a stir plate. While the nanocellulose was stirring, the remaining water was placed in another beaker and colorant was added to that water and stirred with a glass rod. The colorant was added until the desired color was reached using one to three colors. For some trials, some of the water was replaced with ethanol to help disperse the pigment. The water and color mixture was then added to the nanocellulose suspension and stirred for approximately 10 minutes. After stirring, the suspension was poured into a silicone mold and allowed to air-dry for about a week, leaving just the colored film behind. The general experimental method is shown in figure 1.

After experimenting with colorants, the issue of how to apply the nanocellulose films was addressed. Due to their

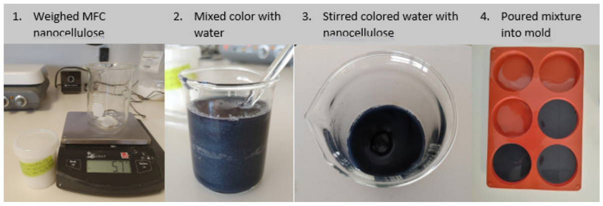

Fig. 1. Simplified procedure for creating air-dried nanocellulose films.

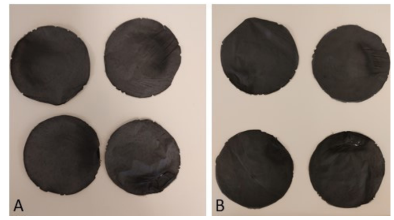

Fig. 3. Trial 1 films. (a) Air side, normal light. (b) Mold side, normal light.

thinness, nanocellulose films are extremely sensitive to moisture. The introduction of moisture can cause the film to warp and tear; therefore, applying the adhesive to the nanocellulose was unsuccessful. Instead, a small dot of adhesive was applied to the support to which the nanocellulose film was to be adhered. Different adhesives were explored, including methyl cellulose, gelatin, Klucel G, and wheat starch paste. During the initial testing to determine how to best adhere the films, a piece of Japanese paper was used as the support. Six of the 14 trials were chosen, along with a control to adhere to the Japanese paper support. These films were chosen because they had the most evenly dispersed colorants, and they came out of the mold easily. Two small pieces of nanocellulose film were adhered using each adhesive. One piece was adhered with the mold side up, and the other was adhered with the air side up since the color and gloss varied according to side in all the samples (fig. 2). The success of each adhesive was assessed based on how well the nanocellulose adhered to the Japanese paper, using as little adhesive as possible to avoid warping the film. Observations were also made in raking and normal light.

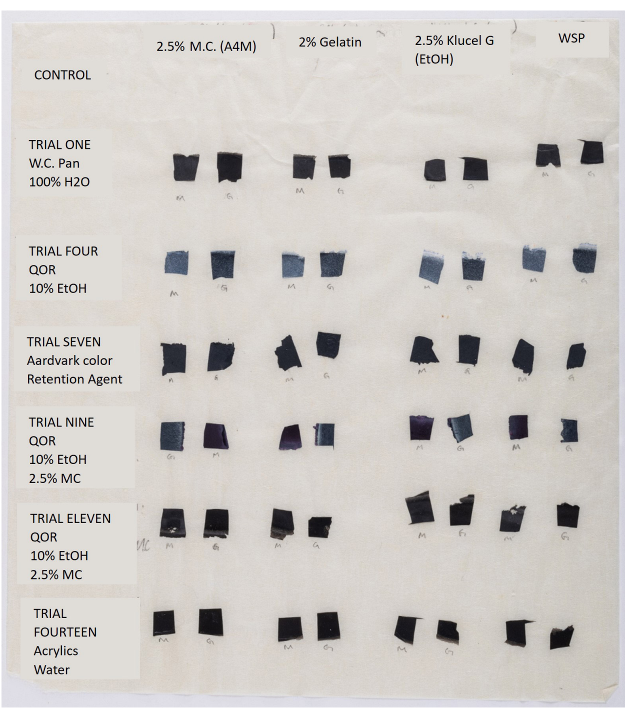

Fig. 2. Application of trials using different adhesives including methyl cellulose, gelatin, Klucel G, and wheat starch paste. The paper was divided so that there were four columns for the different adhesives and five rows of the different colorant trials.

RESULTS AND DISCUSSION

Trials 1 and 2: Water and Kremer Photograph Inpainting Palette

The first two trials were conducted using water and Kremer pigments. The pigment distribution was quite uneven, with the highest concentration in the center of the film. There was also a difference in gloss on the side dried against the mold (or mold side) and the side exposed to the air (or air side). The mold side was noticeably glossier than the air side. Furthermore, when the sheets were removed from the mold, there was a fair amount of pigment transferred to the mold and hands. Images of trial 1 and trial 2 in both normal and transmitted light are presented in figures 3 through 5.

Trials 3, 4, and 5: Water, Ethanol, and QOR Watercolors

Trials 3, 4, and 5 were colored with QOR watercolors because it was easier to get a larger amount of pigment from a tube

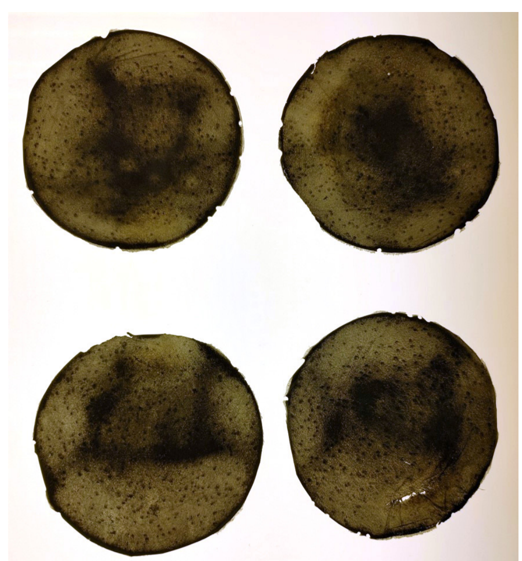

Fig. 4. Trial 1 films, air side, transmitted light.

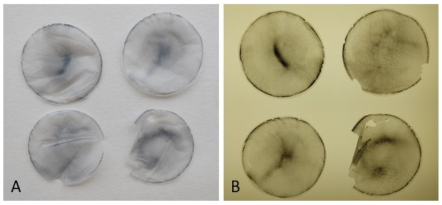

Fig. 5. Trial 2 films. (a) Air side, normal light. (b) Air side, transmitted light.

than a pan and also because QOR watercolors use a binder of Aquazol, which is soluble in water and ethanol. Ethanol was used in these trials in hopes of aiding the dispersion of pigment. As seen in the trial 4 image, there was better pigment dispersion and less pooling in the middle of the films (fig. 6). There remained some difference in gloss between the air and the mold sides, with the mold side having higher gloss.

Trial 5 showed an interesting phenomenon with the air and mold sides differing significantly in color. When the pigments were in suspension, the solution had a warm yellow-gray color similar to a common tone of albumen photographs. Once dry, the air side was gray and the mold side was more yellow. This was due to the individual pigments in the mixture settling differently as the solvent dried (figs. 7, 8).

Trials 6, 7, and 8: Water, Retention Agent, and Aardvark Colors

To address the problems of color offsetting from the dry films and the color change caused by differential pigment settling, Aardvark colors with a retention agent were used for trials 6, 7, and 8. Aardvark colors, first developed by Carriage House Paper, are pigments used specifically for coloring paper pulp. Considering that nanocellulose is essentially purified paper pulp, it seemed like a good option for achieving even color. The Aardvark colors are designed to be used with the Carriage House Paper retention agent, which is a cationic substance that gives the pulp a positive charge. The pigments tend to have a negative charge and therefore will remain affixed to the pulp if the proper quantity of a cationic retention agent has been added.

Although the retention agent adhered the colorant to fibers very well, it also made it extremely difficult to remove the films from the mold. They were decidedly stuck and came

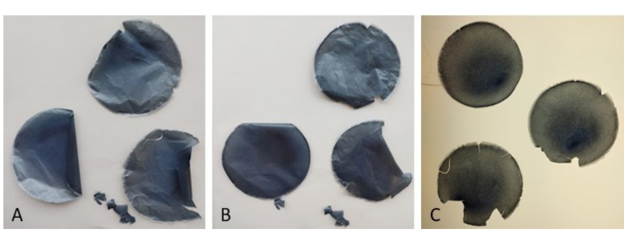

Fig. 6. Trial 4 films. (a) Air side, normal light. (b) Mold side, normal light. (c) Air side, transmitted light.

Fig. 7. Trial 5, air side, normal light. The less dense pigments rose to the top of the film. The final color appears more gray.

out of the mold in several pieces. As seen in figure 9, the films did not come out of the molds easily even when the retention agent was reduced. Furthermore, the films colored with the pigments and retention agent were more opaque, and there

Fig. 8. Trial 5, mold side, normal light. The denser pigments sank to the bottom of the film. The final color appears more yellow.

Fig. 9. (a) Trial 6 films, air side, normal and transmitted light; (b) trial 7 films, air side, normal and transmitted light.

was no color transfer to the mold or hands. Three different colors were also combined to see if differential settling would occur, and none was observed as in previous trials.

Although the trials with the Aardvark colors were not as successful as others because of the difficult removal from the molds, the films were strong and the color distribution was even, so more testing could be conducted using different casting methods, such as casting a larger film using a suction table and silicone-release Mylar instead of a mold.

Trial 9: Water and Ethanol (9:1), 2.5% Methyl Cellulose Sizing, and QOR Watercolors

After the slightly unsuccessful trials with the Aardvark colors, QOR colors were revisited with a slight variation—the addition of 2.5% methyl cellulose as a sizing agent. Methyl cellulose was added to the nanocellulose suspension after the colorant was added. As seen in figures 10 and 11, the distribution of color was fairly even, the films came out of the molds easily, and there was no transfer of color to the mold or hands. Three pigments were used to create a purple-gray color often seen in photographs and to determine if the methyl cellulose would prevent the variation in color from one side to the other. As additionally seen in figures 10 and 11, there is still a difference between the two sides, with the mold side being glossier and lighter gray in color and the air side being more matte and a darker, purple-gray color. Finally, when compared to the others, these films had less drape and behaved more firmly, whereas the trials without methyl cellulose were softer and pulpier.

Trials 10 and 11: Water and Ethanol (9:1), 5% Methyl Cellulose Sizing, and QOR Watercolors

The samples in trials 10 and 11 were created the same way as in trial 9, but instead of 2.5% methyl cellulose, 5% methyl cellulose was used to determine if the distribution of pigment would be different with a higher concentration of the sizing agent. As seen in figure 12, the methyl cellulose pooled in certain areas and caused a water droplet effect throughout the films. Trial 11 also employed 5% methyl cellulose, but it was stirred for another 20 minutes on the stir plate to determine

Fig. 10. Trial 9 films, air side, normal light.

Fig. 11. Trial 9 films, mold side, normal light.

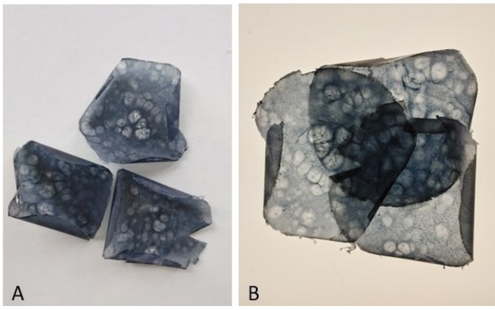

Fig. 12. Trial 10 films, overlapping mold side, transmitted light.

if this would prevent the pooling of the sizing solution. The extra stirring was somewhat successful, but there were still some uneven areas.

Trials 12 and 13: Water, 2.5% Methyl Cellulose Sizing, and QOR Colors

Trials 12 and 13 returned to 2.5% methyl cellulose as the sizing solution since it resulted in a more evenly dispersed film. No ethanol was used in these trials to determine its effect on pigment dispersion. Ultimately, the dispersion for both one and three colors appeared to be the same when using just water or 10% ethanol in water. The variation in appearance between sides was still significant. The air side appeared grayer, whereas the mold side was glossier and yellower (fig. 13).

Trials 14 and 15: Water, 2.5% Methyl Cellulose Sizing, and Golden Acrylics

In the final two trials, acrylic paints were used as a comparison to the QOR watercolors and Aardvark colors since acrylic paints are a familiar material in paper conservation treatments. It was hoped that the trials could answer questions such as how well acrylic paints disperse in the nanocellulose film, if there is a difference in texture and gloss, and if pigment combinations settle unevenly, thus causing a difference between the air side and mold side. The films colored with acrylics had the most even dispersions of all the trials. However, the texture of these films was more plastic-like than the other trials.

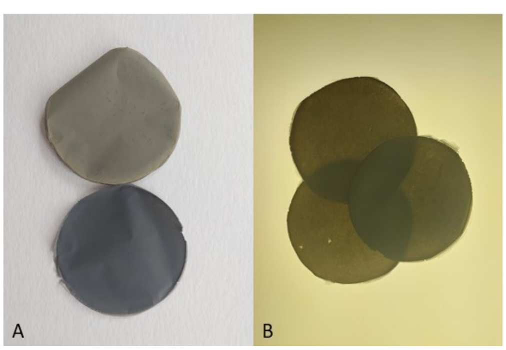

Fig. 13. Trial 13 films. (a) Air side, normal light. (b) Overlapping films, air side, transmitted light.

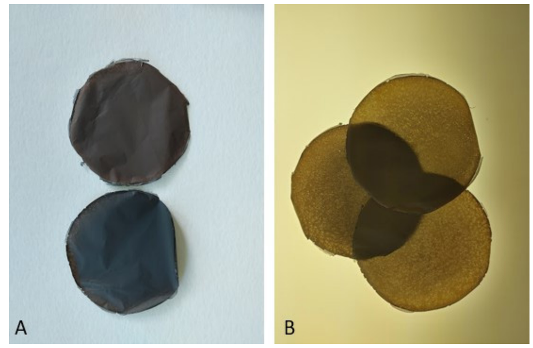

Fig. 14. Trial 15 films. (a) Reddish air side (top) and darker gray mold side (bottom), normal light. (b) Overlapping films air side, transmitted light.

There was also a distinct difference in appearance between the air side and the mold side, with the mold side having a higher gloss and redder hue, whereas the air side was more matte and grayer (fig. 14). Although the texture of the films is fairly different from paper, these films could be used for thin fills on photographs. The acrylic-colored films could be explored for other applications, such as objects conservation.

Results for Application Methods and Adhesive Options

As mentioned earlier, small pieces of nanocellulose film from several trials were cut and adhered to a Japanese paper substrate using several adhesives, including methyl cellulose, gelatin, Klucel G, and wheat starch paste. Due to the thinness of the nanocellulose films, the adhesive could not be applied directly to film and then applied to the substrate like a typical paper mend. Rather, the adhesive was applied to the substrate and then the film was placed on top of the adhesive and dried under Mylar and a weight. Regular Mylar was used, and there was no issue with it sticking; however, silicone-release Mylar could be used as well. It is important to note that the nanocellulose film is quite impressionable when slightly damp, and therefore anything pressed on the film while drying will impart its texture, including a fingerprint. Thus, if a glossy texture is desired, it is necessary to use Mylar or silicone-release Mylar. This does pose an interesting research avenue for fills that require texture. Table 2 summarizes observations made when the films were adhered to the Japanese paper.

Trials on Practice Photographs

Vintage photographs purchased from eBay were used to practice the nanocellulose fill techniques. Several photographs with small emulsion losses were selected. The films from trials 1 through 15 were used to create fills, even if the color was not an exact match. For the first trial on a silver gelatin photograph, the best color match was chosen from trial 14, which used one acrylic paint to color the nanocellulose film. A small piece just larger than the area of loss was cut from the film. Next, a small drop of 2.5% methyl cellulose

	Observations
2.5% Methyl cellulose (A4M)	Adhered well to both nanocellulose and Japanese paper. To keep the gloss on the mold side piece, it needed to be dried under Mylar, not Hollytex. The most distinctive color difference between the mold and air sides was found in trial 4 with the QOR watercolors.
2% Gelatin	Did not adhere as well to the Japanese paper and nanocellulose as the methyl cellulose. Still needed to dry the mold side under Mylar to keep the gloss.
2% Klucel G in ethanol	Dried quickly and did not adhere well to the Japanese paper. Had to reapply adhesive over nanocellulose and dry again.
Wheat starch paste	Fairly wet and caused some warping of the nanocellulose when applied to the Japanese paper. The most distinctive color difference between the mold and air sides was found in trial 4 with the QOR colors.

Table 2. Summary of Observations of Adhesives Used to Adhere Nanocellulose to Japanese Paper

was placed in the area of loss. The nanocellulose film was carefully placed on the adhesive using tweezers. A smooth piece of Mylar was then placed on the fill with a small weight on the top and left to dry for about 15 minutes. Once dry, the Mylar was carefully removed, leaving the nanocellulose film adhered to the area of loss. The excess film was carefully removed around the edges of the loss by gently pulling with tweezers while holding down the fill with Mylar. This left just the nanocellulose film that was adhered to the loss, creating an even fill (fig. 15).

A second warm yellow-gray silver gelatin photograph with loss of both the emulsion layer and some of the paper beneath was chosen for another trial. The film from trial 13 was chosen as the best color match. Trial 13 was one of the trials that produced films with two distinct sides: one was a warm yellow-gray, whereas the other was darker gray. The color of one side was not an exact match with the original photograph, but when two films were layered on top of one another, it was a closer match. In addition, because the area to be filled was deeper than the previous fill, the layered fill helped compensate for the deeper loss. Furthermore, it allowed for preliminary experimentation of layering different colored films to create a desired color. Once laminated together with methyl cellulose and dried under Mylar, a slightly oversized piece of nanocellulose film was placed on a dot of methyl cellulose over the area of loss and left to dry under Mylar for about 15 minutes. Upon removal of the Mylar and excess material, the fill appeared less glossy than the surrounding photograph, so another small dot of methyl cellulose was placed on top of the fill and left to dry under Mylar. When dry, the gloss of the fill was significantly closer to the original photograph, and the overall texture of the fill appeared similar to the orange peel texture of a silver gelatin photograph under magnification (fig. 16). Although the color was not a perfect match, the application technique proved successful based on the overall texture and gloss of the fill.

CONCLUSIONS

Overall, these different trials demonstrate that nanocellulose film can be colored fairly evenly using QOR watercolors, ethanol, and a 2.5% methyl cellulose sizing agent. In addition, when creating nanocellulose films, it would be prudent to create large batches of films with the range of colors and hues that are often seen in photographs, as it takes about a week for the films to dry. Once the films are made, they can be stored in paper folders between sheets of regular Mylar or silicone-release Mylar. The major factors to consider when creating nanocellulose films are as follows:

Fig. 15. First fill application trial on silver gelatin photograph. (a) Missing emulsion on silver gelatin photograph. (b) Matching a prepared nanocellulose film with the photograph. (c) 2.5% methyl cellulose placed on bare spot and nanocellulose overtop with Mylar. (d) Nanocellulose fill dried and excess removed.

Fig. 16. Second fill application trial on a silver gelatin photograph. (a) Missing emulsion on silver gelatin photograph circled in red. (b) Matching a prepared nanocellulose film with the photograph and adhering it with 2.5% methyl cellulose. (c) Another layer of methyl cellulose added on top of the fill and dried under Mylar. (d) Nanocellulose fill on photography, normal light, photomicrograph.

- The difference in gloss between the air side and mold side of the film should be considered.
- Using mixtures of pigments can cause a difference in color from the mold side to the air side.
- Application of the nanocellulose films works best when the adhesive is applied to the substrate rather than the film itself.
- Overlapping nanocellulose films of different colors can create the desired hue.
- If a glossier surface is desired, cast the fill against a smooth surface like Mylar.

Figure 17 summarizes trials 1 through 15, demonstrating the differences in color, gloss, and texture for the different colorants used.

Finally, there is much potential for future research on nanocellulose films as a colored fill material, including different

Fig. 17. Overview and comparison across trials for both mold and air sides in a combination of normal and raking light.

casting methods, such as using a suction table, which may help prevent the differential settling of pigments. Another area of exploration is casting films of various thicknesses against different textures, which could then be used to create fills for textured photographs or other objects. Nanocellulose is a useful tool in paper conservation with great potential for further exploration to expand its capabilities within the field.

ACKNOWLEDGEMENTS

This research project would not have been possible without the support of the entire Cleveland Museum of Art conservation team. They were always willing to discuss my tests and suggest new ideas for different colorants to try. A special thanks to Moyna Stanton, my supervisor at the Cleveland Museum, for her inspiration and willingness to help me along the way. I would also like to thank Robin Canham and Rachel Mochon for their research in nanocellulose and their commitment to collaborate and share their own findings with me during the course of this project. Next, I would like to thank my current institution, the American Antiquarian Society, for not only encouraging me to finish my research but also providing financial support so that I was able to share my findings at the AIC Annual Conference. Finally, a big thank you to AIC for awarding me the speaker stipend, which made it possible for me to attend the conference.

APPENDICES

Trial 4 Procedure: QOR Watercolors, Water, and Ethanol
QOR watercolor paints were combined with 9:1 water and ethanol and CNF, then cast and left to dry. The goal of this trial was to determine the following:

- How does ethanol affect opacity?
- Does adding ethanol help disperse the pigment?
- Does the color of the solution remain the same once dry?

Procedure:
4.18 g CNF
72.81 mL water
8.09 mL ethanol
28.4 mL of CNF suspension added to each mold

1. Measure 4.18 g of CNF in a 200-mL beaker.
2. Using a 100-mL beaker, add 8.09 mL of ethanol.
3. Add water to the 100-mL beaker containing ethanol until the 50-mL mark is reached.
4. Tare the scale and place the 100-mL beaker of ethanol on the scale, then add the QOR watercolor paint, noting the weight of each color as added:
   a. 0.1 g iridescent pearl
   b. 0.1 g Paynes gray
5. Add the rest of the water to the 100-mL beaker (it weighed a total of 80.9 mL).
6. Add the ethanol and water mixture to the measured CNF and stir.
7. Use a stir rod and stir plate to mix the suspension for about 15 minutes.
8. Measure 28.4 mL of CNF suspension, and pour it into one of the molds.
9. Repeat for the remaining two molds.
10. Let sit for about a week to dry.

Trial 6 Procedure: Aardvark Color, Water, and Retention Agent
Aardvark color and retention agent were used to color the CNF before it was cast and dried. The goal of this trial was to determine the following:

- How does the combination of retention agent and colorant affect opacity?
- Does the retention agent help with dispersion and adherence of pigment to fibers?
- How does the pigment disperse in the dried sheet?

Procedure:
4.62 g CNF
80.4 mL water
0.31 g retention agent
0.31 g wet pigment slurry
28.4 mL of CNF suspension added to each mold

Thickness: 0.0105 mm

1. Measure 4.62 g of CNF into a 400-mL beaker.
2. Measure 40.2 mL of water into a 100-mL beaker.
3. Add 0.31 g of the retention agent to the water in the 100-mL beaker.
4. Add the solution of water and retention agent to the pulp mixture in the 400-mL beaker. Allow it to stir on a stir plate for 10 minutes.
5. Add the following proportions of pigments to the other half of the water (40.2 mL) in a 100-mL beaker:
   a. 0.11 g titanium dioxide
   b. 0.2 g carbon black
6. Combine the pigment and water solution with the pulp suspension. Stir for 10 minutes on the stir plate.
7. Pour 28.4 mL of the suspension into a 30-mL beaker.
8. Pour the measured colored suspension into a 9.5-cm-diameter silicone mold.
9. Repeat filling the other two molds in the same way.
10. Let sit with a domed paper cover to help prevent large changes in airflow from the AC system and to prevent dust from settling on the film (it took about a week for the water to evaporate).

Trial 9 Procedure: QOR Watercolors, Water, Ethanol, and 2.5% Methyl Cellulose Sizing

This trial was based on correspondence with Rachel Mochon, who had some success adding 5% methyl cellulose (A4M) to the colored mixture of nanocellulose and water.

Procedure:

4.18 g CNF
72.81 mL water
8.09 mL ethanol
2.09 g of 2.5% methyl cellulose
28.4 mL of suspension added to each mold

1. Measure 4.18 g of MFC into a 200-mL beaker.
2. Add half the water (36.4 mL) to the MFC in a 200-mL beaker.
3. Add 2.09 g of 2.5% methyl cellulose (A4M) to the MFC and water mixture. Stir for 10 minutes on a stir plate.
4. Place the other half of the water (36.4 mL) into a 100-mL beaker, and add 8.09 mL of ethanol.
5. Add about 0.2 g of QOR watercolors (three different colors), and stir with a glass rod until the desired color is reached.
6. Pour the watercolor mixture into the MRC mixture, and stir on a stir plate for 10 minutes.
7. Pour 28.4 mL of the stirred solution into each mold (three molds).
8. Let air-dry for about a week.

Trial 14 Procedure: Acrylics, Water, 2.5% Methyl Cellulose Sizing

As a comparison to the watercolors, a trial using acrylic paint was conducted. The goal of this trial was to determine the following:

- How well do acrylic paints disperse in nanocellulose that is sized with methyl cellulose?
- Is the texture different from the previous trials conducted with watercolors and Aardvark colors?
- How is the gloss and color different from the films colored with watercolors?

Procedure:

4.18 g CNF
80.9 mL water
2.09 g of 2.5% methyl cellulose
28.4 mL of suspension added to each mold

1. Measure 4.18 g of CNF into a 400-mL beaker.
2. Add half the water (40.0 mL) to the CNF in the 400-mL beaker.
3. Add 2.09 g of 2.5% methyl cellulose (A4M) to the mixture of CNF and water. Stir for 10 minutes on a stir plate.
4. Place the other half of the water (40.0 mL) into a 100-mL beaker.
5. Add about 2 g of QOR watercolor (three colors), and stir with a glass rod.
6. Pour the watercolor mixture to the MFC mixture, and stir on a stir plate for 10 minutes.
7. Pour 28.4 mL of the stirred solution into each mold (three molds).
8. Let air-dry for about a week.

REFERENCES

Abitbol, Tiffany, Amit Rivkin, Yifeng Cao, Yuval Nevo, Eldho Abraham, Tal Ben-Shalom, Shaul Lapidot, and Oded Shoseyov. 2016. "Nanocellulose, a Tiny Fiber with Huge Applications." *Current Opinion in Biotechnology* 39: 76–88. https://doi.org/10.1016/j.copbio.2016.01.002.

Canham, Robin, Alison Murray, and Rosaleen Hill. 2013. "Some Practical Aspects of Nanocellulose Film: Characterization, Expansion and Shrinking Tests, and Techniques to Create Remoistenable Nanocellulose." *Restaurator: International Journal for the Preservation of Library and Archival Material* 44 (3): 177–203. https://doi.org/10.1515/res-2022-0031.

Dreyfuss-Deseigne, Rémy. 2017. "Nanocellulose Films in Art Conservation." *Journal of Paper Conservation* 18 (1): 18–29. https://doi.org/10.1080/18680860.2017.1334422

Völkel, L., K. Ahn, U. Hähner, W. Gindl-Altmutter, and A. Potthast. 2017. "Nano Meets the Sheet: Adhesive-Free Application of Nanocellulosic Suspensions in Paper Conservation." *Heritage Science* 5 (1): 23. https://doi.org/10.1186/s40494-017-0134-5.

Völkel, L., Prohaska, T., and A. Potthast. 2020. "Combing phytate treatment and nanocellulose stabilization for mitigating iron gall ink damage in historic papers." *Heritage Science* 8: 86. https://doi.org/10.1186/s40494-020-00428-6

SOURCES OF MATERIALS

Aardvark Colors – Carriage house pigments – carriagehouse-paper.com/supplies/pigments-additives/pigments
CNF Nanocellulose – umaine.edu/pdc/nanocellulose/
QOR Watercolors – www.dickblick.com/brands/qor/
Silicone Molds – amazon.com

AUTHOR INFORMATION

MARISSA MAYNARD
Library and Archives Conservator
American Antiquarian Society
185 Salisbury St.
Worcester, MA 01604
Mmaynard@mwa.org