Article: Where Tradition Meets Technology: Utilizing Microfibrillated Cellulose (MFC) as a Reinforcement Material in Fan Conservation
Author: Kathryn Boodle
Source: Book and Paper Group Annual 41, 2022
Pages: 1-8
Editors: Kimberly Kwan, Managing Editor, and Roger S. Williams, Assistant Editor Editorial Office: bpgannual@gmail.com
ISSN: 2835-7418

The *Book and Paper Group Annual* is published once each year by the Book and Paper Group (BPG), a specialty group of the American Institute for Conservation (AIC). It was published in print from 1982 to 2021, and transitioned to a digital publication in 2022. All issues are available online at https://culturalheritage.org.

Print copies of back issues are available from AIC. All correspondence concerning back issues should be addressed to:

American Institute for Conservation
727 15th Street NW, Suite 500
Washington, DC 20005
info@culturalheritage.org www.culturalheritage.org

KATHRYN BOODLE

Where Tradition Meets Technology: Utilizing Microfibrillated Cellulose (MFC) as a Reinforcement Material in Fan Conservation

INTRODUCTION

In recent years, the conservation field has seen a rise in the use of nanocellulose as a viable solution for fine repair of heritage materials. The ability to cast thin, translucent sheets of nanocellulose either alone or imbued with an adhesive makes them a good alternative for repair on semi-translucent substrates or double-sided objects. As with any technique that utilizes near invisible repairs (e.g., fine fiber stitch [Miller 2010]), they take practice to use and are helpful in specific situations, but should not be viewed as a total replacement for traditional mending. There are some situations where the merging of nanocellulose with traditional methodology can be beneficial and play off the strengths of all materials for the improved life of the object.

While the catch-all term for the material tends to be known colloquially as nanocellulose, this term may refer to materials that are broken down to the microfibril or nanofibril size during processing (Dreyfuss-Deseigne 2017b). In the available literature, nanocellulose may also be referred to as microfibrillated cellulose (MFC), nanofibrillated cellulose (NFC), cellulose nanocrystals (CNC), bacteria cellulose (BC), etc., in an effort to more specifically identify the source material used to create it and the process by which it was formed (Dreyfuss-Deseigne 2017b; Dreyfuss-Deseigne 2018). The various types of nanocellulose available for conservation all have their pros and cons depending on the final result desired by the treatment. Rather than discussing the various differences between available nanocelluloses, this article will focus on MFC and examine its use in the treatment of three paper fans.

MFC is composed of cellulose chains that have had their hydrogen bonds forcibly separated by a mechanical process and put in an aqueous suspension to retain a few cellulose compound units linked together in a dispersion. This dispersion consists of long, flexible entangled fibers containing both crystalline and amorphous regions, providing both flexibility and strength to the cast film used in treatment. After processing to the microfibril level, these fibrils are between 5–30 nm in diameter and an average of 1–3 μm in length. This can vary based on the original source material and how the cellulose was processed. The source materials that can be used to create MFC can be a variety of plants: softwood, hardwood, bamboo, cotton, linen, etc. Impurities from wood, such as lignin or hemicellulose, are removed prior to or during the processing of the material to ensure stability (Dreyfuss-Deseigne 2017a; Dreyfuss-Deseigne 2017b). The 2.6% Celova Nanogel, manufactured by Weidmann Fiber Technology, was selected for this project as it was easy to acquire, budget friendly, and easy to manipulate in its gel form.

FAN CONSERVATION: TREATMENT APPROACHES AND LIMITATIONS

Before delving more deeply into the use of MFC with traditional mends, it is important to understand the construction of a fan and how preserving its functionality can limit treatment options. Fans are made of wooden sticks that are joined together at the head by a rivet. These sticks usually narrow at the point where they enter the fan package, becoming the ribs or slips (Maxson 1986). The fan package is made of two separate sheets of paper sealed at the top edge with a ribbon made of paper (or fabric) that helps hold the paper together when the individual fan leaves are folded for movement. The fan papers are attached to the inserted ribs with adhesive rather than to each other, which creates a series of air pockets around the ribs and on the non-adhered leaves (fig. 1). This localized attachment and air pocket network is crucial to the fan's ability to function and move. The fan is protected when closed by two wooden guards at either end, which are usually thicker than the sticks and polished or lacquered depending on the design. The guards help to both keep the fan closed and aligned, while acting as a lever when opening the fan (Maxson 1986).

Papers presented during the Book and Paper Group Session, AIC's 50th Annual Meeting, May 13–18, 2022, Los Angeles, California

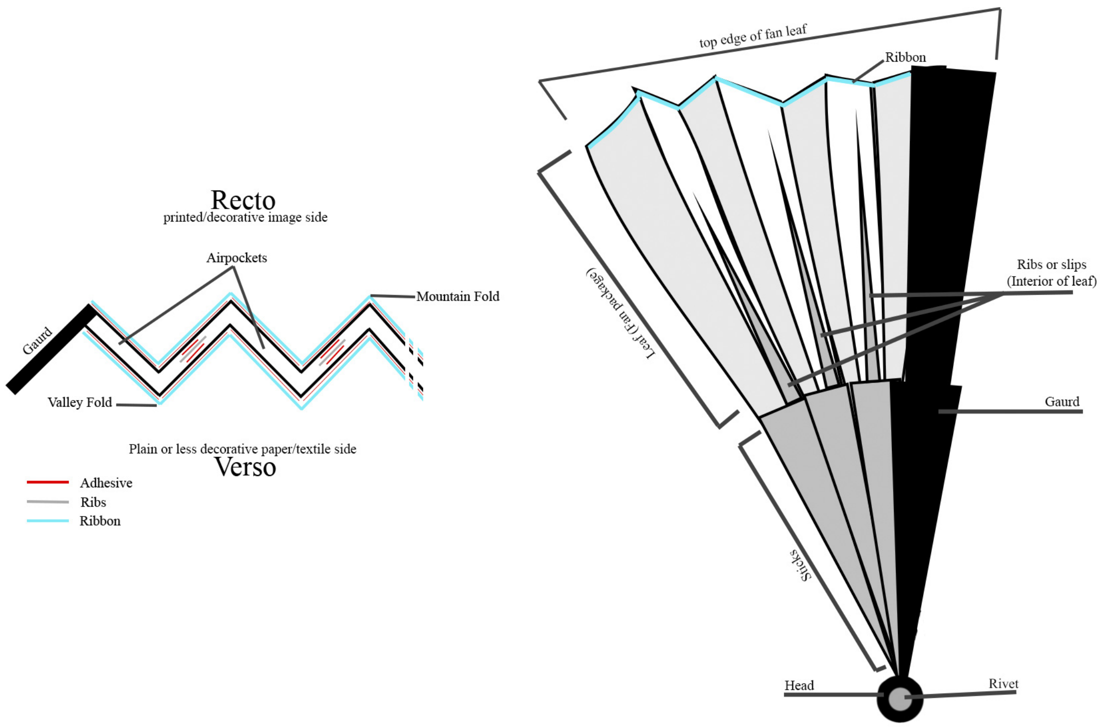

Fig. 1. Diagram illustrating the interior attachment of the fan ribs to the paper package (left) that need to be preserved during mending and the parts of a fan overall (right).

Unless the fan is completely deconstructed for aqueous or intensive stabilizing treatment due to extensive damage, the conservator must work in a limited space and utilize protective methods to preserve the air pockets in the fan packet. If space permits, polyester strips can be used to help insert repair tissues between the recto and verso papers. The polyester helps preserve the air pockets within the fan leaves by ensuring the repair paper only adheres to one side of the fan packet. Given the rigidity of the heavier polyesters (i.e., 4 or 5 mil), there may be a risk of exacerbating the tear along the mountain and valley folds with this method. As an alternative, silicone release paper or film may be used as it can be easier to shape and insert given its thinness and flexibility in comparison. The protective support, be it polyester or silicone release film, needs to have a section that extends beyond the edge of the fan papers so that it can be removed easily once the repair is fully dry. Since these protective supports block moisture and prevent adhesion of the repair to maintain the air pockets within the fan leaves, drier adhesives and desiccated blotters should also be used when applying the repair to avoid tidelines along the folds.

Another factor for consideration with the treatment of fans is how much the added thickness of the repair may affect folds and the function of the fan post-treatment, much like when guarding a bound volume and monitoring for swelling of the spine. A thinner repair tissue is better as it reduces undesirable structural change to the fan, but it can be challenging to apply cleanly to the repair area when visually it is not easily discernible from the protective support described above. Minor stress testing of the area by opening and closing the fan after drying is one of the few ways to confirm correct adhesion and repair.

A final note in preparing for treatment is to take into account the overall support of the fan during repair. During this phase, the fan needs to be supported so that the folds are preserved while providing a strong base for the repairs to be dried under weight. Custom supports of 4-ply rag board that mimic the mountain peaks of the fans were used during treatment in the case study, with dowels to control the height and movement of the supports (fig. 2). These supports were critical for maintaining not just the folds, but also paper alignment during mending. Snake weights helped to hold the object in place though heavier bag weights were also utilized to set the repair tissue. The amount of weight needed to set each repair varied and, as for many paper-based items, was largely based on the thickness and quality of the primary substrate. For example, with the fans in the case study, the recto paper was a thicker good to moderate quality paper used for lithographic printing while the verso paper was a thin decorative lacquer-like paper of poor quality. While the lithographic paper was repaired with an 11 gsm kozo that needed bag weights to be fully affixed, the black lacquer-like paper needed a 5 gsm kozo

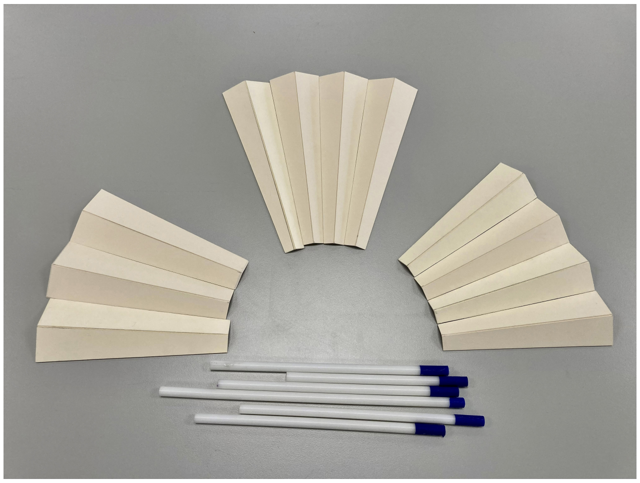

Fig. 2. Support pieces and dowels used during conservation treatment.

with only the snake weights due to its thinness, although it did require tighter control of moisture and was less forgiving of mistakes for similar reasons.

Overall, when treating a fan for repair using Japanese tissue paper, it is important to note that there will be significant paper manipulation within a very compact area. This takes time to complete as one should not work on adjacent folds at the same time and must wait for each area to fully dry before testing the repair and continuing. Working in this manner will avoid stressing the piece unnecessarily, limit the duration under which folded areas are weighted during repair, and preserve the fan folds.

TESTING WITH CELOVA NANOGEL FOR LOCAL REPAIR

Conservators may be familiar with the work by Remy Dreyfuss-Deseigne on casting MFC into films for nearly invisible repairs on transparent or semi-transparent papers. While these films have several benefits, a cast MFC film for repair of the fans was only briefly considered as a viable treatment alternative to traditional mending. After initial tests on mock ups, several points of concern arose for using this method on the actual object. First, when inserted into the fan package, it still required a comparable level of manipulation to mend the tears as when using a Japanese tissue. As such, this would not eliminate any of the treatment concerns or improve handling of the damaged areas in a meaningful way. Second, if the film was applied on top of the torn or split areas, it would still be visible in certain lighting. Additionally, while testing was only conducted on blank paper, there were concerns that a repair applied on top of the actual object could cause media discoloration or local tidelines. Lastly, if the strip was applied on top, there was concern around how the cast film would withstand the movement required to allow the fan to open and close. Since there is not much information available on nanocellulose films being flexed, it was uncertain whether the repair would either fail too easily over time or be too durable and cause breaks in the paper when manipulated. In consideration of the above concerns and the time required to create and apply cast MFC films correctly, it appeared that cast MFC films would not be optimal for use on three-dimensional objects that need to move semi-frequently.

While the use of MFC as a cast film was of little interest for the purposes of fan treatment for the reasons above, it was also discovered that MFC can also be applied directly to an object in its gel form to form a local mend. Rémy Dreyfuss-Deseigne mentioned this repair method of direct application in passing during the FAIC-hosted workshop, "Applications in Nanocellulose Films in Conservation," held at the Museum of Fine Arts, Boston in July of 2018. He explained that MFC reestablishes strong hydrogen bonding within the fibrils of the cellulose matrix as it dries, which in turn allows it to also form hydrogen bonds with the cellulose of the paper it has been applied to (Maloney 2019). No further explanation or experimentation of this method was done during the workshop as its primary focus was on cast films. Based on this anecdotal information, it was believed that the direct application of MFC in gel form had potential to limit stress and manipulation of the fan in areas of minor or partial breaks along the fold lines without compromising the overall fan package. Since a search of the available literature did not yield additional information on methodology,[1] testing was carried out on samples to see if it was a feasible option for at least some, if not all, of the fan repair areas.

Weidmann Fiber Technology's Celova Nanogel is available in concentrations of 3%, 10%, and 30%, although the exact concentration in each order may vary slightly. The container of Nanogel that was ordered by NEDCC was marked at a concentration of 2.6% (fig. 3). On Weidmann's website,

Fig. 3. 2.6% Celova® Nanogel used during treatment.

the 3% is listed as "microfibrillated cellulose in suspension" and is much closer to a gel than the 10% and 30% which are powdery and advertised as a "microfibrillated cellulose paste" ("Celova" 2019; "Native Microfibrillated Cellulose" 2015).

After Amanda Maloney attended the nanocellulose workshop mentioned above, she shared information on the workshop with NEDCC staff, who then made a series of cast films for practice and testing. The slurries for these films were later used as the basis for testing with direct application methods of MFC. A paper of comparable thickness to the fan's facing paper was found, folded, and torn along the fold to imitate a break in the fan package. These papers were then each mounted to the 4-ply rag supports that would be used during fan repair. The slurries used for testing were as follows:

- 1:1 mixture of 2.6% Celova® nanogel: (1:4 ratio) wheat starch paste
- 2.6% Celova® Nanogel, undiluted
- 0.2% Celova® Nanogel slurry in filtered water
- 0.2% Celova® Nanogel slurry in filtered water with Winsor and Newton Lamp Black Gouache
- 0.2% Celova® Nanogel slurry in ethanol
- 0.2% Celova® Nanogel slurry in 1:1 ethanol: filtered water
- 0.2% Celova® Nanogel slurry in 1% methylcellulose
- 0.2% Celova® Nanogel slurry in 1:1 2% Klucel G:1% Klucel M in ethanol

Because the samples were just small sections of paper, they needed to be restricted to imitate the fan package and were held in place with low tack tape at the ends of each paper to shaped supports (fig. 4). A single layer of each solution was applied directly with a 00 sable brush to the breaks in the papers and were allowed to dry completely—a process that appeared to take approximately 3 hours for the 0.2% slurries

Fig. 4. Paper samples mounted to the fan supports during testing.

and 12 hours for the undiluted nanogel. As when casting the films, the samples could not be moved or adjusted during this time and had to remain where they were so as not to disrupt the nanocellulose.

The 0.2% Celova Nanogel slurries in ethanol and in 1:1 ethanol: filtered water did not join together at all, even after a secondary application. No further testing was done with these options after this point. All other samples appeared to repair the tear by pulling the paper back together and were moved to the stress testing phase. While the 0.2% Celova® Nanogel slurries in filtered water, 1% methyl cellulose, and 2% Klucel G:1% Klucel M appeared to be good options at first, they broke easily after they were manipulated several times as if they were part of a moving fan. To confirm the mechanical failure was not a result of insufficient drying time, samples were prepared a second time and allowed to dry overnight. The results were slightly improved, but these samples still broke after manipulation. Given that the failure required more manipulation of paper than would be considered "normal" handling for a flat paper object, there may be some potential in using these slurries as direct applications on targeted repair areas in other heritage materials.

The 1:1 mixture of 2.6% Celova Nanogel: wheat starch paste and undiluted 2.6% Celova Nanogel held up best both when applied and when manipulated like a fan. These samples took longer to fully dry in comparison to the others. However, as they were more visually noticeable when applied, it was also much easier to determine when they had fully dried as they became nearly invisible and decreased significantly in size. Given their visual thickness on application, a few other tests were conducted to determine what was the smallest amount that could be applied for a stable repair.

As a final test, a small sample of the two slurries were applied in an unobtrusive area on one of the fans. It was quickly noted that the undiluted 2.6% Celova® Nanogel was too wet and would cause minor tidelines if used for treatment. The slurry was removed with desiccated blotters and dried rapidly. The 1:1 mixture worked much better, as the addition of wheat starch paste assisted in decreasing the ratio of water in the gel enough to prevent any tidelines on the pieces. Through the initial tests, it was determined the 1:1 mixture would be most suitable for targeted applications of isolated failure points or in areas that cannot be easily accessed. In some ways, this perhaps makes the repair done in this treatment closer to a consolidation of the paper fibers rather than a mend via hydrogen bonding as described by Dreyfuss-Deseigne.

CASE STUDY: THREE GILBERT AND SULLIVAN FANS

The three fans in this case study are souvenir items from the early 1900s depicting scenes from Gilbert and Sullivan's *The Mikado*, *H.M.S. Pinafore*, and *Pirates of Penzance*. The fans were

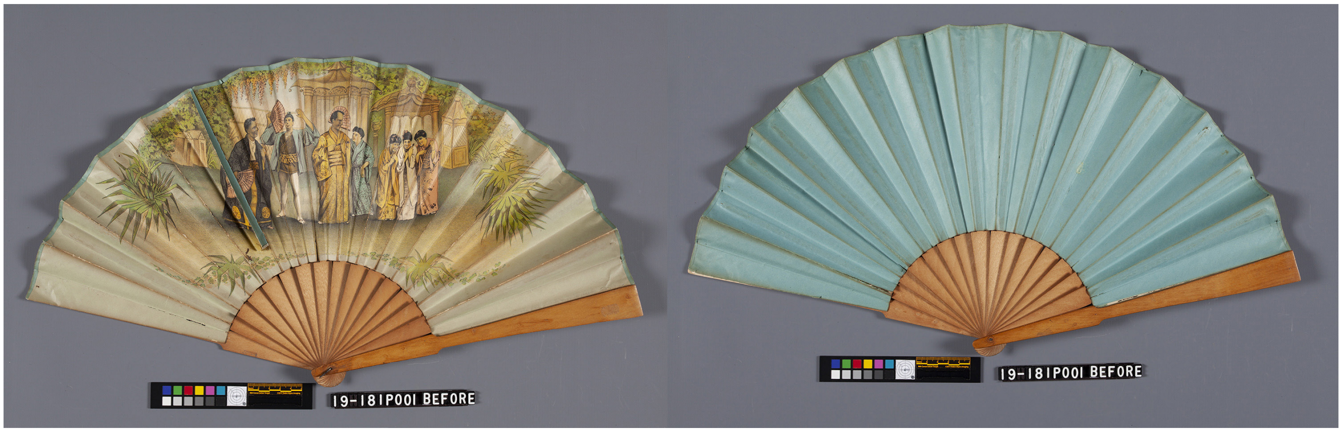

Fig. 5. *The Mikado*, before treatment.

printed using lithography or chromolithography with *Pinafore* having the addition of gold gilt surrounding the image. The *Pinafore* and *Pirates* fans had a black lacquer-like decorative paper as the verso paper on their fan package, while *The Mikado*'s was a blue toned wood pulp paper. The gilt and lacquer papers were approached with caution as they were unforgiving and would stain easily or become matte if too much water was applied with both MFC direct applications and traditional mends.

Although varying in degree, the fans all had similar types of damage. In the fan for *The Mikado* (fig. 5), there were multiple areas of weakened paper and minor loss near the guards, which is a point of high stress in the opening and closing of the fan. On the left half of the recto paper, the paper was split along the mountain fold through part of the image and torn perpendicular to this fold. Other tears were present along the peaks of the outermost leaves though they were not as obvious at first glance. The fan for *Pirates of Penzance* (fig. 6) had breaks that tore both of the fan papers. Additionally, it had one unfortunate tear and misalignment that was causing the sticks to function improperly just left of the center. Of the three fans, the *H.M.S. Pinafore* (fig. 7) was the most damaged with two complete breaks, numerous partial tears, abrasion to the gold gilt, and splitting of the mountain peaks on the fan package. In some ways, the extensive damage on *Penzance* and *Pinafore* would have made it easier to do some of the traditional repairs as the full breaks allowed for access to the interior of the fan leafs.

As mentioned earlier, supports for each fan matching the width and angle of the fan leaves needed to be made prior to beginning treatment. The head and tail of the fans were measured carefully so that 4-ply rag board could be cut, scored, and folded to match the folds of each fan. Wedges of Hollytex and blotter were also prepared to assist with drying repairs and preventing them from accidentally adhering to the supports. The 4-ply rag supports had long Delrin dowels inserted underneath. By pulling or pushing the dowels under the fan support, the height of each leaf could be controlled in a gentle manner to accommodate the slight lift of the fan package while also providing a firm support for the weight

Fig. 6. *Pirates of Penzance*, before treatment.

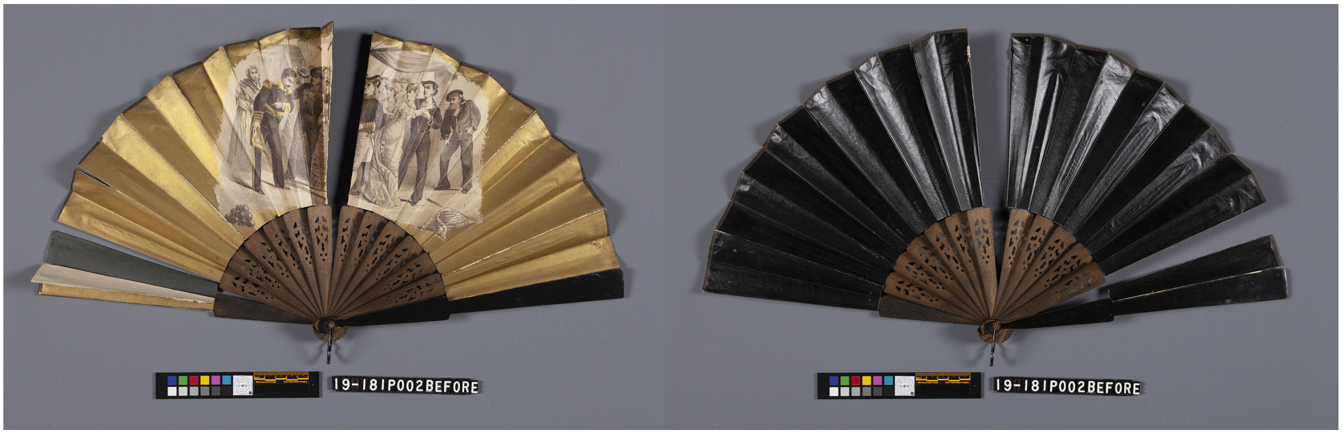

Fig. 7. *H.M.S. Pinafore*, before treatment.

that would go on top of the fan. While Delrin was used for this treatment, small diameter wooden dowels (5–8 mm) or other similar sticks would also be suitable for use.

Although significant durability and flexibility was observed during testing on the trial samples, there was still concern as to whether the direct application of MFC would stabilize the fans adequately in areas of severe breaks, as seen on the *Pinafore* fan. As these items are owned by a private client, it is safe to assume that they will be handled more regularly than if they were owned by an institution. As such, the areas of complete separation had the addition of a handmade Tengujo 9 gsm Japanese tissue paper repair applied in a traditional manner first.

On the *Pinafore* and *Pirates* fans, the repairs to the interior of the fan leaf were done in stages. The Japanese paper repairs were first attached along the length of the break with one tissue repair on opposite sides of the recto and verso papers and allowed to dry. Once dry, the fan was placed on the 4-ply rag supports and lined up to complete the repair by first connecting the two halves of the verso paper, allowing it to dry, and then repeating the process with the recto paper and the addition of a protective silicone film barrier support between the two sheets of paper. Once dry, the protective support was removed and the reconstruction of the fan package was complete with the exception of minor breaks (fig. 8).

On *Mikado*, where there were only partial or breaks only on the recto paper, the repair tissue was attached in one go by first tucking it under the rib side of the fan leaf, aided by an angled polyester strip, before the area was boned down to ensure a good attachment. The papers and polyester were then manipulated so they fit into the interior of the leaf between the recto and verso papers. As a final step, the two sides were then aligned as much as possible using the mat board support to recreate a gentle angle (fig. 9). These Japanese tissue mends were allowed to dry completely under local weight before approaching the repair and reinforcement with the nanocellulose and wheat starch paste mixture.

Fig. 8. Local isolated repairs on *H.M.S. Pinafore* with toned tissue.

As the Celova® Nanogel and wheat starch paste mixture dried out rather quickly, it was made in small batches for immediate use on each of the three fans as needed. This also provided the opportunity to control the amount of moisture

Fig. 9. Repair with Japanese tissue paper on *Mikado*.

Fig. 10. In progress repair with Celova® Nanogel: wheat starch paste mixture on *H.M.S. Pinafore.*

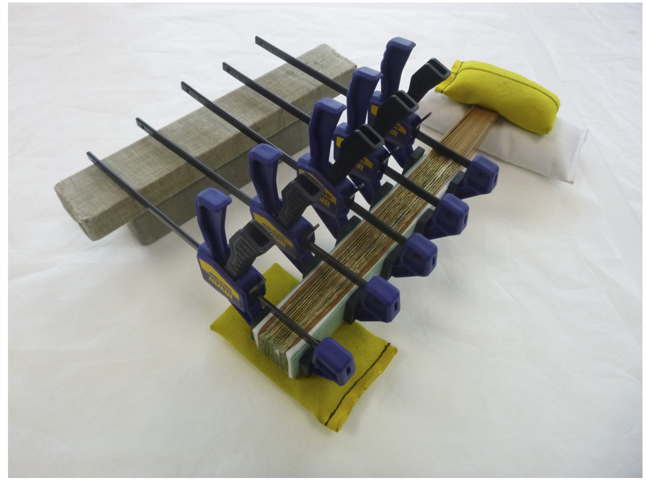

Fig. 11. Clamped fan post treatment.

more tightly if needed, as was the case when addressing the gilding on *Pinafore*. It was decided to use the mixture on areas that were weakened and would break in the future or those areas that were already broken but would be very difficult to access without extensive manipulation of the fan package and could result in damage. As such, rather than applying it along the entire length of the mountain or valley fold, it was only applied to areas that showed extensive fraying and appeared heavily worn (fig. 10). In some cases, the fan paper needed to be held in place for about 10 to 15 minutes to "set" the Celova Nanogel. In others, the paper had to be manipulated slightly for a better alignment of paper fibers. Neither manipulation of the fan paper was as extensive as what needed to be done for the traditional mends. After the initial application, the fan could not be moved or manipulated for at least 24 hours without causing some failure to the repair. Each repair was tested to ensure limited visual change in the surface as well as overall strength and ensure it was not causing further fracturing or paper splitting along the fold.

The final stage of treatment was to clamp the fans under pressure to fully introduce the folds to the repaired areas and re-familiarize the fans with how to open and close after they had been manipulated during treatment for so long (fig. 11).

CONCLUSION

The use of the nanogel mixture on the three fans allowed for decreased overall manipulation of the fan package to strengthen areas that were difficult to access or were showing signs of paper fraying. It created a strong invisible repair that did not inhibit the functionality of the fan when opened or closed. While solvents, watercolor, and synthetic adhesives were not added to the nanogel mixture used in this case study, Celova Nanogel blended well with these materials during initial tests and a combination of these materials with nano gels may be suitable for flat paper objects. Given that the undiluted 2.6% Celova Nanogel was only rejected for use in this case study due to being too wet for the fan paper, there is also a possibility that it may be used without further modification in other treatment scenarios for invisible repairs on par with techniques such as the fine fiber stitch methodology (fig. 12).

While nanogel was used successfully to consolidate areas of minor tears and fraying in this case study, its use should be considered carefully as it can be challenging and requires practice to apply appropriately. There is also significant downtime while the nanogel dries, which makes it unideal for objects that cannot remain out for long periods of time

Fig. 12. After treatment photos of the three fans.

or where opened items without adequate support can be strained. As with any treatment, conservators should weigh their options and utilize techniques that play off the strength of the materials to provide reinforcement and support of the objects in our care.

ACKNOWLEDGMENTS

Many thanks to Amanda Maloney for sharing the information that she learned at the Applications of Nanocellulose in Conservation Workshop 2018 at the Museum of Fine Arts, Boston when she was a member of staff at NEDCC. Thanks also to the client, Donald J. Smith, for allowing me to present on the project at the annual meeting and in the BPG Annual.

NOTE

1. At the 50th annual meeting it was mentioned to the author in passing that there were articles in French by Rémy Dreyfuss-Deseigne on using the direct application technique that was mentioned at the Nanocellulose workshop. While the author has not found these articles yet due to a lack of time, she believes it is important to include this note for those who may wish to find them or to reach out to Mr. Dreyfuss-Deseigne directly with more questions on the technique as she is not an expert on MFC.

REFERENCES

"Celova: Microfibrillated Cellulose & Powders." Weidmann Fiber Technology, November 20, 2019. https://weidmannfibertechnology.com/products/.

Dreyfuss-Deseigne, Rémy. 2017a. "Nanocellulose Films in Art Conservation." *Journal of Paper Conservation* 18: 18–29.

Dreyfuss-Deseigne, Rémy. 2017b. "Nanocellulose Films: Properties, Development, and New Applications for Translucent and Transparent Artworks and Documents." *The Book and Paper Group Annual* 36: 108–114.

Dreyfuss-Deseigne, Rémy. 2018. "Applications in Nanocellulose Films in Conservation," Workshop sponsored by the Foundation for Advancement in Conservation, Museum of Fine Arts-Boston, MA, July 19–20, 2018. Information shared as part of the Northeast Document Conservation Center's internal Professional. Development Program by Amanda Maloney, January 2019.

Maloney, Amanda. Associate Photographic Conservator at NEDCC, in conversation with the author, 2019.

Maxson, Holly. 1986. "Design and Construction of a Support for a Folding Fan." *The Book and Paper Group Annual* 5. https://cool.culturalheritage.org/coolaic/sg/bpg/annual/v05/bp05-04.html

Miller, Ann-Marie, and Lesley Hanson. 2010. "The Maker and the Monk: Conservation of the *Mercator Atlas of Europe.*" *Journal of the Institute of Conservation* 33: 29–39.

"Native Microfibrillated Cellulose for Wide Range of Applications: WMFCQ_Advanced" Leaflet, Weidmann Fiber Technology, 2015. https://weidmannfibertechnology.com/wp-content/uploads/2015/10/WEIDMANN-Fiber-Technology_WMFC_Q_advanced.pdf

SOURCES FOR MATERIALS

Celova® Nanogel
Weidmann Fiber Technology AG
Neue Jonastrasse 60
8640 Rapperswil
Switzerland
+41 (0)55 221 49 60
https://weidmannfibertechnology.com/

ALL OTHER MATERIALS

Talas
330 Morgan Avenue
Brooklyn, NY 11211
(212) 219-0770
https://www.talasonline.com

AUTHOR INFORMATION

KATHRYN BOODLE
Senior Conservator
Northeast Document Conservation Center (NEDCC)
Andover, MA
Kboodle@nedcc.org