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ORIGINAL RESEARCH OR TREATMENT PAPER

Conserving Animation Cels: Reattaching Loose Paint Without Adhesive

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ABSTRACT
A collaborative research project between the Getty Conservation Institute and the Walt Disney Animation Research Library investigated storage and conservation treatment strategies for animation cels. Animation cels are transparent plastic sheets inked on the front and painted on the reverse. Common damage observed on aged cels is cracking, loss of adhesion, dislocations, and losses of the paint. In practice, flaking paint of animation cels is often removed and repainted rather than consolidated. Being reverse painted, paint consolidation of animation cels adds another layer of complexity to established approaches to paint consolidation. One important component of this study has involved developing minimally invasive treatments for reattaching delaminating paints, which involved studying paint condition, characteristics, and properties. This paper presents recent innovations in paint reattachment that rely on the intrinsic hygroscopic properties of the cel paint formulations. The new treatment is a multi-step approach that manipulates paint properties by using precise levels of relative humidity, established within a humidity chamber, in order to reactivate the paint and reattach it. A major advantage of this method is that a consolidant is not necessary. Method development and a case study procedure are presented in depth. The method developed is effective for cel paints with the same or similar formulations.

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Animation cels; consolidation; reattachment; paint reactivation; paint delamination/ detachment; adhesion loss; gum arabic; cellulose acetate; humidity; case study; Walt Disney

Introduction

An animation cel is a transparent plastic sheet of cellulose nitrate, cellulose diacetate, cellulose triacetate, or polyester on which characters or objects are inked and/or painted by hand. Typically, inks are applied to the viewing side (front) and paints are applied to the back (reverse) of the sheet (Figures 1 and 2). Characters are reproduced onto the sheet from drawings created by animators. The Walt Disney Ink & Paint Department formulated their own gum arabic-based paints between 1936 and 1986. The paints were also diluted into inks, before being superseded by Xerographic outlines. Animation cels are typically placed over a background image and photographed on motion picture film, along with a series of other animation cels that together depict phased movements of the figures (Getty Research Institute n.d.). Playing back usually at 24 frames per second gives the illusion of motion which means that roughly half a million finished cels were needed for 80 min of film (Thomas and Johnston 1981). Having served their initial purpose, animation studios tended to discard animation cels after production, to sell them in limited quantities, or to wash and reuse the plastic sheets (Witkowski 1994). Since the mid-1980s, animation cels are no longer seen as simple functional items created solely for the purpose of making a movie, but rather as works of art in their own right (Mikulak 1995). Serving as historical, technological, and cultural documents of their time, archivists and conservators are faced with questions of preservation and conservation.

A collaborative research project between the Getty Conservation Institute (GCI) and the Walt Disney Animation Research Library (WDARL) was established to improve conservation strategies for animation cels by investigating the effects of storage environment on their condition (Getty Conservation Institute 2021) and developing new approaches for minimally invasive conservation treatment of damaged paints.

One of the more common types of deterioration in animation cels is paint becoming detached from the plastic substrate. Even during their production, adhesion of paints to the sheets was an issue (WDARL 1936; Bailey 1956). In the past cels were sent back to the Ink & Paint department to get repainted. This approach is still in practice today: the original

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Figure 1. *The Jungle Book,* 1967: front, normal light. ©Disney Enterprises, Inc.

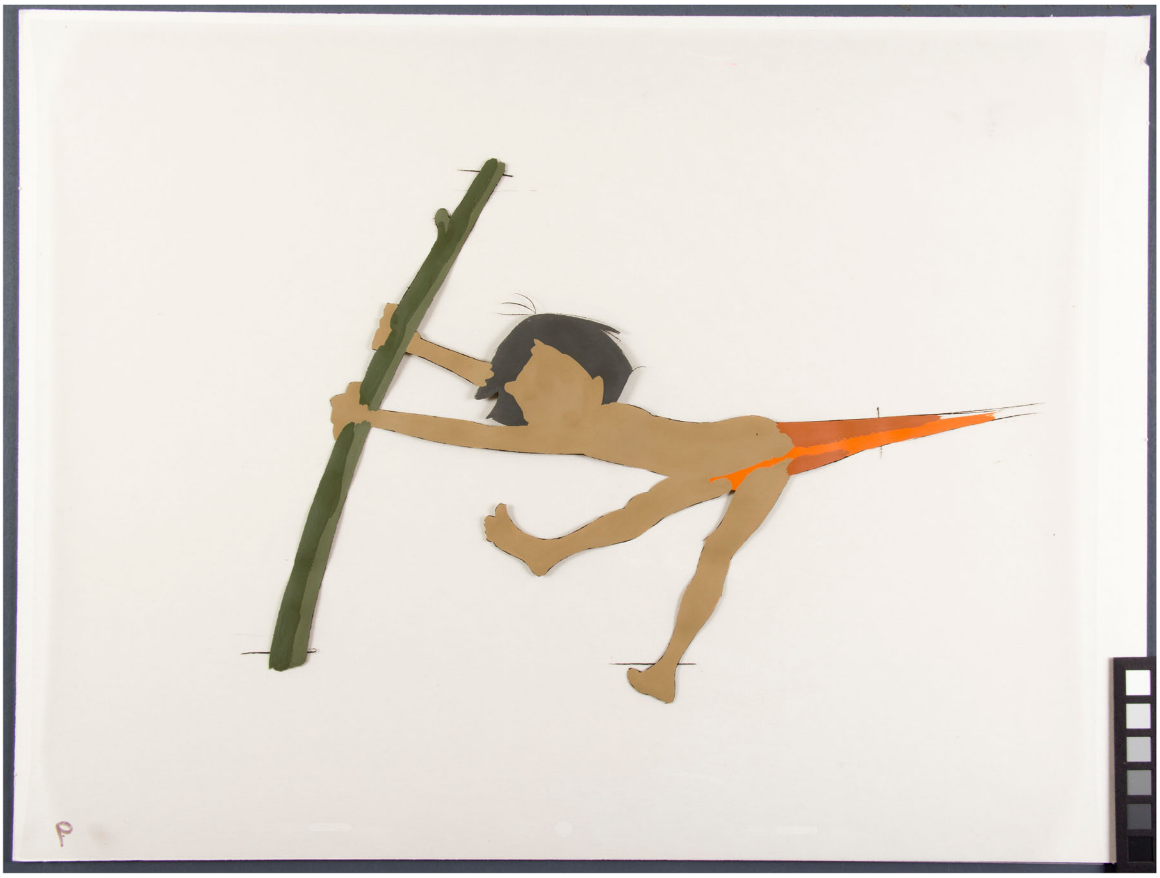


Figure 2. *The Jungle Book,* 1967: back, normal light. ©Disney Enterprises, Inc.

paint is color matched, and detached areas are removed and repainted (Worth and Stude 1989; Barbagallo 1995, 104; Höyng 2010, 309; Combemale 2014; S/R Laboratories n.d.).

However, recognizing animation cels as historical, technological, and cultural documents of their time, it was felt that alternative approaches to re-attaching paint should be explored, that fall more in line with established guidelines of the conservation profession (ECCO 2003; ICOM 2017). A pioneer in taking a less-invasive approach in the 1980s is Linda Witkowski, writing about '… a variety of humidity situations and/or resin-based adhesives that can be considered for the conservation of damaged paint layer on the cel'. The paint was then reattached by flowing in small amounts of ethanol (Witkowski 1984, 78). In this context Worth and Stude 1989 wrote: 'In some cases, paint that is slightly dehydrated can be re-bonded to the cel by means of slow exposure to humidity.'. Other animation cel conservators seem to have taken on this path (Animation Art Conservation n.d.).

Attention to a scholarly approach to animation cel conservation has been limited and only arisen within the past decade. In recent years interventive conservation research at the Deutsches Institut für Animationsfilm (DIAF), the Filmmuseum Potsdam, and the Cinémathèque Française produced case studies for consolidating flaking paint of animation cels. At the DIAF, alkyd resin and polyvinyl-acetate paints were consolidated using Degalan® PQ611[1] in aliphatic hydrocarbons (Höyng and Rapoport 2011, 221). This consolidant was also used at the Filmmuseum Potsdam for the consolidation of gouache paints (Lörzel 2016, 113). At the Cinémathèque Française humidity was used for paint consolidation after the example of the GCI-WDARL project (Lemaire 2020). Another approach considers the use of practically invisible nano-cellulose, applied between paint and sheet with the consolidant Klucel® G in ethanol and Aquazol® 200 (Dreyfuss-Deseigne 2017, 112). Today's scholarly approaches to paint consolidation differ, though the main aspect of preserving all original material is the main goal.

The principle aim of this study was to investigate the possibility of minimally invasive treatments for delaminating paint of Walt Disney animation cels. This was achieved by studying paint characteristics, properties, and condition through a condition survey, archival information, and analytical techniques. These results lead to exploring approaches of reactivating the paint binder through changes in relative humidity rather than consolidation, as the least invasive approach possible. Developed methods were implemented and evaluated in case study treatments, both of which will be discussed. This conservation treatment study focused on gum arabic paints on cellulose diacetate sheets, which represents the bulk of the animation cel collection at the WDARL. Most of the research was undertaken on paints from the 1960s using deaccessioned cels that were available as test specimens. Though this research was conducted on Walt Disney animation cels, there is a possibility, with further study, that other animation cels with similar paint formulations could be treated using the same or a similar approach.

Materials

Ink and paint characterization: composition – properties – damages

Condition survey – archival documentation – analytical verification

Between 1936 and 1986, the Disney Ink & Paint Department formulated their own gum arabic-based paints. Developments in paint formulations during this period were recorded in lab notebooks, recipes, and other documents housed at the WDARL. Thus, archival documentation and a condition survey of the animation cel collection at the WDARL set the baseline for many aspects of this study, which were subsequently verified analytically. A detailed paint characterization description that included damages is published in 'Observations from a Condition Survey of Walt Disney Animation Cels' (Hoeyng et al. 2016) and summarized in the following.

A condition survey of a representative group of animation cels proved to be an invaluable tool for guiding observation of their condition across the timespan of their production and for characterizing ink and paint materials and the plastic sheets. Based on information obtained from this survey, three main time periods were established that reflect the materials and characteristics of the paints (Figure 4). For productions between 1937 and 1942,[2] paint properties vary in thickness and surface texture. These early paints seem more brittle than paints from later periods. Productions from about 1948–1953 show a transition, in which paints have distinct thicknesses but still varying texture and surface sheen, either appearing grainy and matte, or smooth and semi-glossy. Paints from productions between 1961 and 1985 are characterized by flexibility and uniform thicknesses. Surfaces of these later paints are very smooth and have a satin sheen.

Archival documents reveal precise paint formulations and ingredients for the timespan of their production. Although the basic recipe stayed similar over the years, alterations were made. According to a representative recipe from 1938, an early binder composition contained gum arabic binder, glycerin as humectant, Santomerse S as surfactant, and Dowicide™ A as preservative, in a pigment-to-binder ratio of 1:1. For the transition period from the mid-1940s to the mid-1950s, a change of

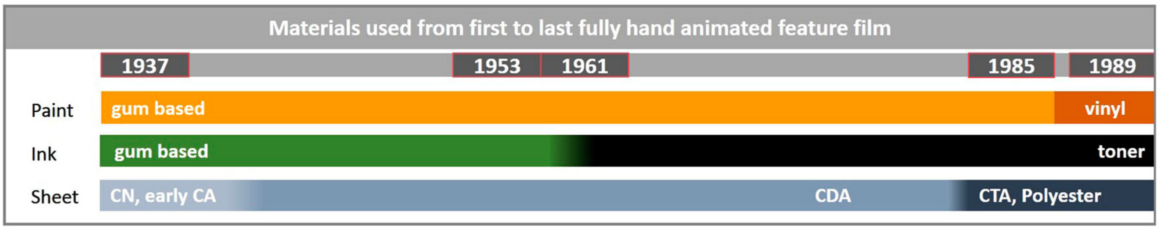


Figure 3. Paint, ink, and sheet materials used at the Walt Disney Ink & Paint Department.

humectant to sorbitol was found, listing a product called Arlex. Starting in the mid-1950s and fully implemented in the early 1960s a sorbitol derivative (1,4-anhydro-D-glucitol) was added in addition to sorbitol. For the later paint period (between 1961 and 1985), a typical recipe lists gum arabic binder, Arlex as humectant, AquaLoid® as surfactant and Dowicide™ A as preservative, in a pigment-to-binder ratio of approximately 1:2. Thus, typical later paints contain twice the amount of binder compared to the early paints. Observations of time periods from the condition survey can be correlated to binder concentration and humectant types, as seen in archival documents verified by GC-MS analysis.

Common damages observed in paints are cracking, loss of adhesion, dislocations, and losses. A general trend of paint damages for production cels[3] can be drawn from the condition survey, with the greatest amount of damage seen in the earlier paints and the least amount in the later paints. This observational timeline of paint damages correlates well with changes in paint characteristics and composition.

For inks, all cels were hand-inked from 1937 to 1953. To make colored inks, the paint was diluted with a mixture of water and Santomerse S, a surfactant. Around the late 1950s, the studio began making the transition to Xerographically produced outlines[4] (Figure 3). Ink defects such as ink losses or transfers to the interleaf paper were mostly observed on hand-inked outlines and rarely on Xeroxed outlines.

Paint properties as a function of relative humidity

Archival documentation – macro scale – micro scale – nano scale

Correspondence found in archival documents highlights the paint properties at a time in relation to the relative humidity (RH). Early documents from the 1930s reveal an adjustment in paint composition according to typical RH levels throughout the year. '… we will have our paints so adjusted gradually that there will not be such a serious problem of all the paints popping off at once' (WDARL 1936). A later document from the 1950s states: 'If humidity goes under 35%, paint will dry out and flake off cel. If it goes over 45%, paint will become sticky again' (Bailey 1956).

These sources led to the investigation of paint properties as a function of RH on a macro- to micro- to nano scale on paints from Walt Disney's animated feature *The Jungle Book*, 1967. On a macro-scale, paint properties were studied using a deaccessioned cel which was exposed to a series of RH conditions at room temperature. The cel was placed in a transparent acrylic chamber and the RH was adjusted using saturated salt solutions, starting at about 58% RH, and in about 10% RH steps decreasing down to 13% RH and increasing to about 72% RH. Responses of the cel to these changes in RH were recorded photographically and assembled into a time-lapse video. In its extremes, the paint started detaching below 30% RH from a preexisting small detached area,

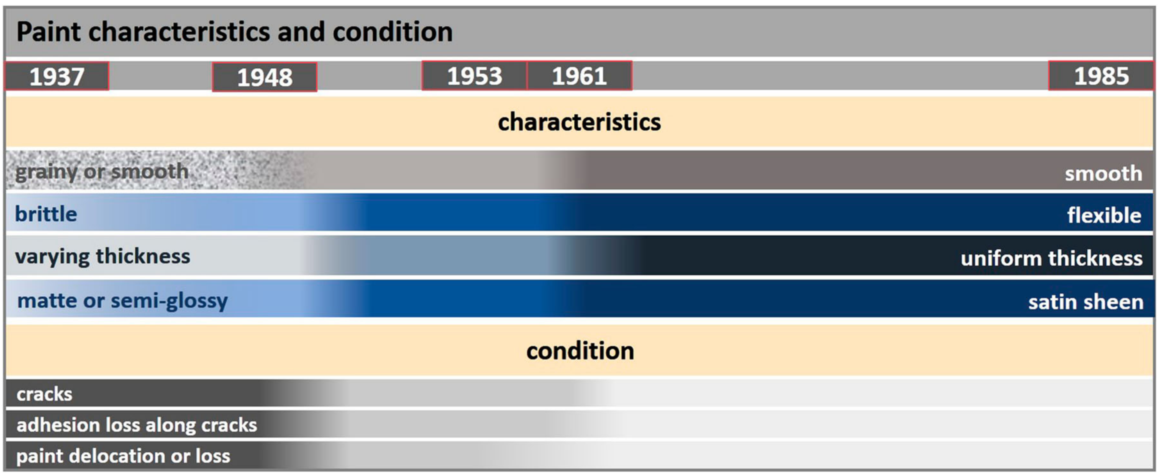
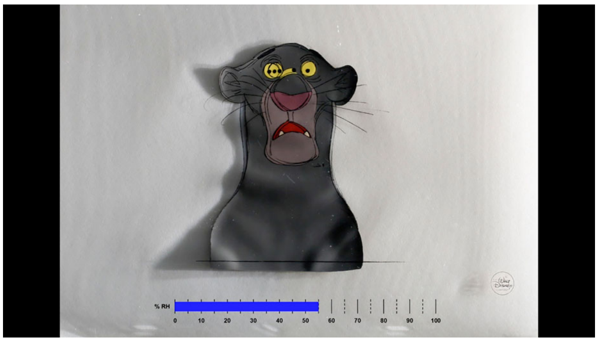


Figure 4. Characteristics and condition of paints made at the Disney Ink & Paint Department.

and with even lower RH reaching across the entire width of the paint. On the ascending cycle above 55% and with higher RH, the paint started reattaching itself, almost returning to its previous condition (Video 1 in Supplemental Data) (Beltran et al. 2017).



Video still 1: Video showing paint properties as a function of relative humidity on a macro scale for paints from ca. 1961 – 1985. Here: *The Jungle Book*, 1967. © Disney Enterprises, Inc.

To further investigate the hygroscopic nature of the paint, a simple indentation test was performed on a micro-scale. At specific levels of RH and after allowing time for equilibration, selected paints were tested within an environmental chamber. Indentation started at 82% RH going down to 32% RH in about 5% RH steps. The round tip of an insect needle was pushed into the paint using a constant force measured by an electronic scale underneath. Around 80% RH and above, the paint became almost fluid, but regained its firmness as the RH was reduced (Figure 5). At 35% RH and below, no indent is visible, though observations from the front show that below 50% RH, the paint delaminated partially in the areas where pressure was applied.

On a nano-scale, atomic force microscopy (AFM) was used to analyze the surface adhesion of sub-millimeter samples of an animation cel when exposed to a range of RH conditions. While the adhesion force for the cellulose acetate support and gum arabic-based paint samples demonstrated limited change across a range of RH conditions, the significant increase in the work of adhesion for the paint surface at high RH conditions suggests a loss of cohesion in this layer, indicating a transition from a brittle to a ductile (gel-like) state of gum arabic above 60% RH (Beltran et al. 2017).

These experiments on paints from *The Jungle Book*, 1967 clearly confirm descriptions from archival documentation and visually show the powerful impact of changing RH on the paint, from brittle in low RH to flowable in high RH. These paint properties are crucial for the treatment approach.

Sheet characterization and properties

Investigating the material composition of the sheets, information from an earlier study was used for reference (Giachet et al. 2014; McCormick et al. 2014) and complemented with insights from the condition survey and archival information. As a result, a transition of the use of sheet material is seen from cellulose nitrate (CN) and early cellulose diacetate (CDA) – used from 1937 to the early 1940s – to exclusively cellulose diacetate – used from the mid-1940s to about 1982 – to cellulose triacetate (CTA) and polyester – used from 1983 to the present (Figure 3).

This conservation treatment study focused on paints on CDA sheets. Common sheet plasticizers for CDA are diethyl phthalate (DEP) and triphenyl phosphate (TPP). CDA degrades primarily by hydrolysis, but is also affected by chain scission and photo-oxidation. In hydrolysis, the acetyl side-chains of the CDA polymer reacts with environmental moisture in the presence of an acid catalyst to form volatile acetic acid, leading to an auto-catalytic reaction (Adelstein et al. 1992, 341–342, 346; Carta 2019, 85; Mazurek et al. 2019, 7). The loss of acetic acid causes the CDA plastic sheets to shrink (Nishimura 2015, 3–5).

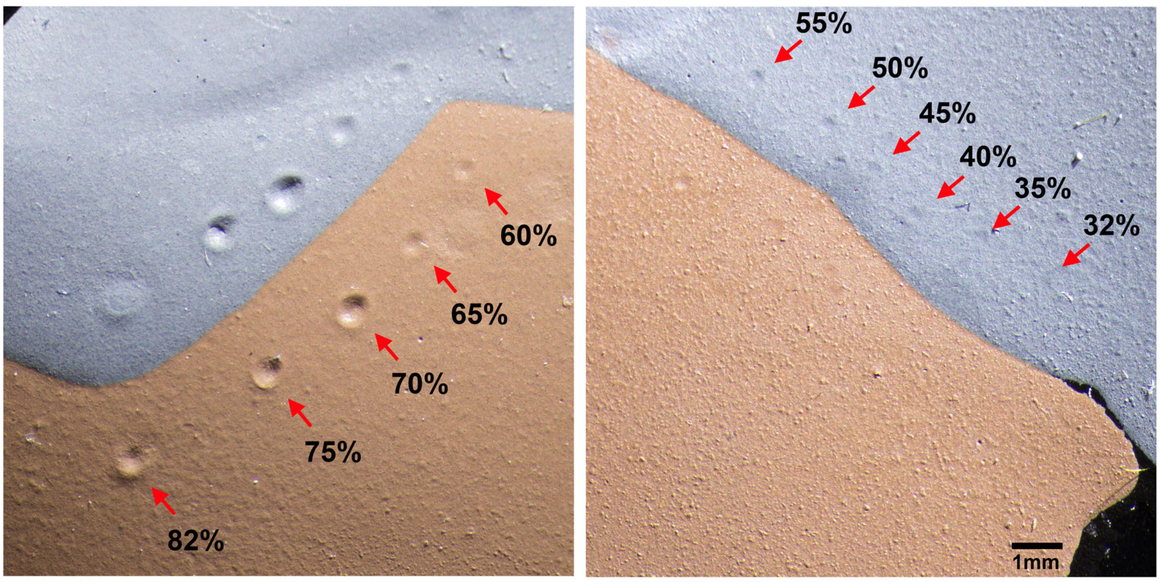


Figure 5. Micro-indentation at specific relative humidities. Detail, *The Jungle Book*, 1967. ©Disney Enterprises, Inc.

Looking at solubility parameters of non-degraded cellulose acetate (CA), non-solvents are aliphatic hydrocarbons, aromatic hydrocarbons, many alcohols, many esters, and water (Horie 2010, 407), although water does lead to hydrolysis of the CA. The typical sheet plasticizers DEP and TPP can be swollen and displaced under the influence of water and many other organic solvents (Gächter and Müller 1993, 357, 376f, 408–411). Only aliphatic hydrocarbons do not dissolve these plasticizers. If solvents are used in any way, their impact on the sheet needs to be considered.

Method development

Consolidation versus reattachment

Optically, an animation cel can be compared to a reverse painting on glass. In both cases, the viewer looks at areas of paint through the clear substrate, to which it is applied. Paint detachment from the sheet can be detected from the viewing side and has to be worked on from the back. If paints are consolidated, the adhesive may also be visible from the viewing side.

Consideration of the paint composition, its properties as a function of relative humidity, and the comparison to a reverse painting on glass, led to ideas of exploring approaches of paint reactivation rather than consolidation. The benefits of paint reactivation relative to consolidation are obvious and the biggest advantage is reversibility. As no new material is introduced, the adhesion created between paint and sheet will never be stronger than its original bond. Considering that the paint often had issues in adhering to the sheet (WDARL 1936; Bailey 1956), adhesion strength is a very important factor to take into account. Looking at a system that is highly susceptible to changes in environmental conditions, responses to RH, and temperature fluctuations of the paint and sheet also have to be considered. The paint's sensitivity to RH and temperature fluctuations will remain after paint reactivation. In contrast, the sorption and desorption of a consolidant is different from the original materials, which could form a moisture barrier where long-term effects are unknown. A consolidant has to fulfill several criteria such as the correct refractive index, no change in saturation of the paint, and remaining clear and transparent with aging. Paint reattachment through reactivation by definition means that the binder will be reactivated to act as a consolidant. Even though paint reactivation might lead to swelling and inner migration processes of the paint's components, it should not lead to any visible changes.

Every conservation treatment will induce changes to the original object. Careful considerations of advantages and disadvantages of a material to be used or an approach to be taken are crucial in decision making. Successful paint binder reactivation to secure paint layers is described in conservation literature (Hansen 1994, 47 and 53; Odegaard and Pool 1999, 592). This minimally invasive approach is adopted in this study for animation cels.

Paint reactivation tests

The WDARL kept a number of deaccessioned cels, which are original production cels. Fortunately for this study, a few deaccessioned cels from *The Jungle Book,* 1967 were available as test specimens. These test cels were prepared with rectangular test areas of 0.5 × 1.5 cm, in which the paint was separated from the sheet at 71–73% RH using a flat brush and kept attached at one short end (Figures 6 and 7). Silicone-coated Mylar was placed between the paint film and the sheet.

Based on our understanding of the hygroscopic properties of the paint as a function of RH, several methods

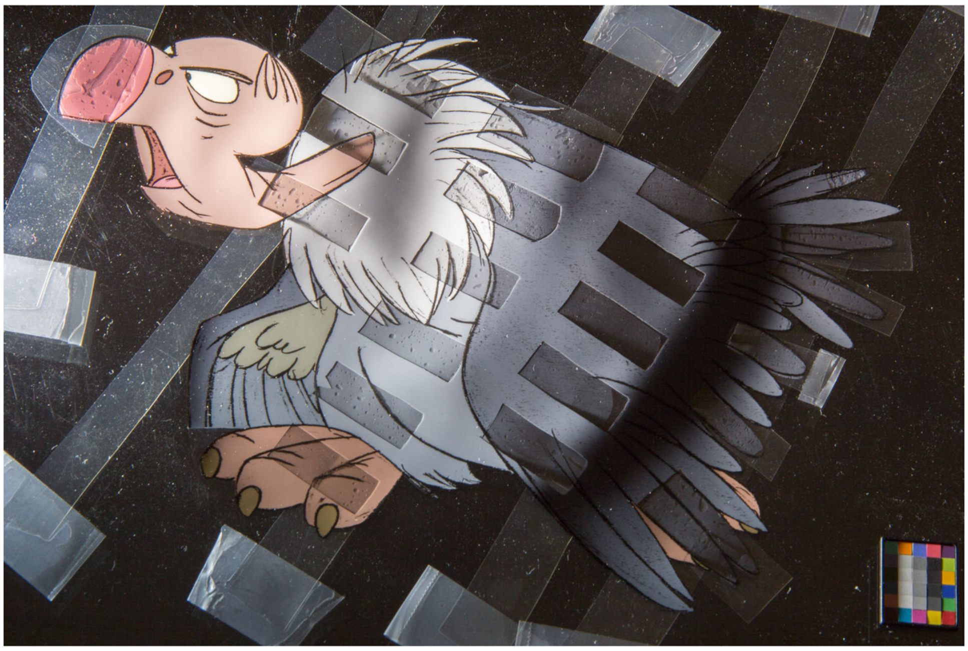


Figure 6. Front, raking light, rectangular test areas. ©Disney Enterprises, Inc.

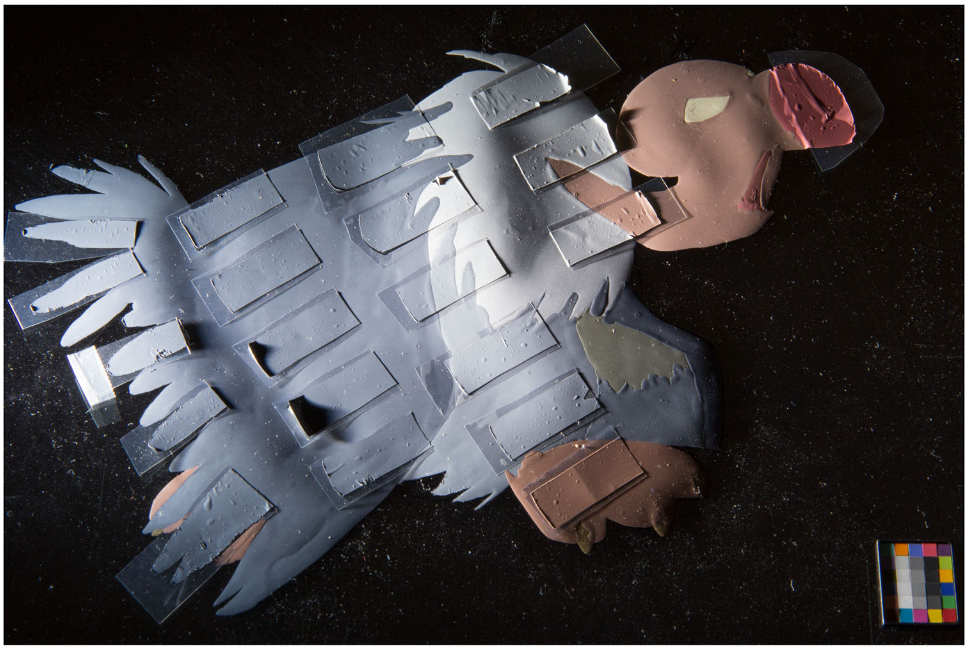


Figure 7. Back, raking light, rectangular test areas. ©Disney Enterprises, Inc.

were considered in reactivating the paint binder. It was important to find the right reactivation point of the paint binder, and reactivate it enough without dissolving the paint. Two approaches were tested, in parallel and in combination with each other. The first aimed to introduce polarity by solvents, and the second targeted the sorption of environmental moisture within a humidity-controlled chamber. For both, the influence of a range of application techniques and drying conditions were explored.

Initial solvent tests were undertaken on the sheet and paint with solvents commonly used in conservation: deionized water; alcohols: ethanol, isopropanol, butanol; aliphatic hydrocarbons: isooctane, Shell OMS[5]; aromatic hydrocarbon: Shellsol A100.[6] The visual findings were consistent with the literature showing that CA is stable only with aliphatic hydrocarbons. Visually water leads to sheet distortions and alcohols lead to plasticizer extraction of the sheet. Testing the paint, it was obvious that polarity was needed for paint reactivation, though water used in liquid form dissolves the paint in an uncontrolled manner. Polar solvents increased the flexibility of the paint, but did not fully reattach it. As expected, no change was observed using aliphatic hydrocarbons, though the adhesion loss increased using isooctane. Aromatic hydrocarbons led to dissolution of the Xeroxed outlines.

Following the results for the solubility of the paint, each test cel was dedicated to one RH at which the humidity of the chamber and polar solvents in different application and drying techniques were tested (Table 1). Solvents were applied to the seam of where the paint is still attached, slowly moving the applicator out as the paint was smoothed down using a silicone tip tool. Using a brush, solvents were applied by letting a drop wick in. Utilizing filter paper, solvents were transferred to the seam. An ultrasonic mister was used to facilitate the application of a solvent mist. The use of both the filter paper and ultrasonic mister aimed to minimize the amount of solvent introduced, thus reducing its impact. Samples were allowed to dry with and without pressure. The main evaluation criteria during treatment were the paint flexibility and handling properties, and after treatment the presence of air bubbles and sheet swelling. The observations were recorded during treatment as well as two days, weeks, and months after treatment in written documentation and with macroscopic images.

Best results were obtained at 70% RH or slightly higher utilizing the RH of the environment also in conjunction with either isopropanol or Sorbitol 1% in isopropanol applied by filter paper and left to dry without pressure. Few, if any, tiny air bubbles were visible

Table 1. Test cels at a specific relative humidity at which different solvents in different application and drying techniques were tested.

RH	Test cel no.	Solvent / Additive	Application btw. paint and sheet	Application on top of paint	Drying
53%RH	BB63	None	Fluid by brush	Silicone tip tool	Pressure
70%RH	140	Ethanol	Fluid by filter paper		No pressure
75%RH	63	Isopropanol	Mist by ultrasonic mister		
80%RH	77	Isopropanol + H^20			
		10 + 0.5ml			
		10 + 1.0ml			
		10 + 1.5ml			
		Sorbitol 1% in Iso-propanol			

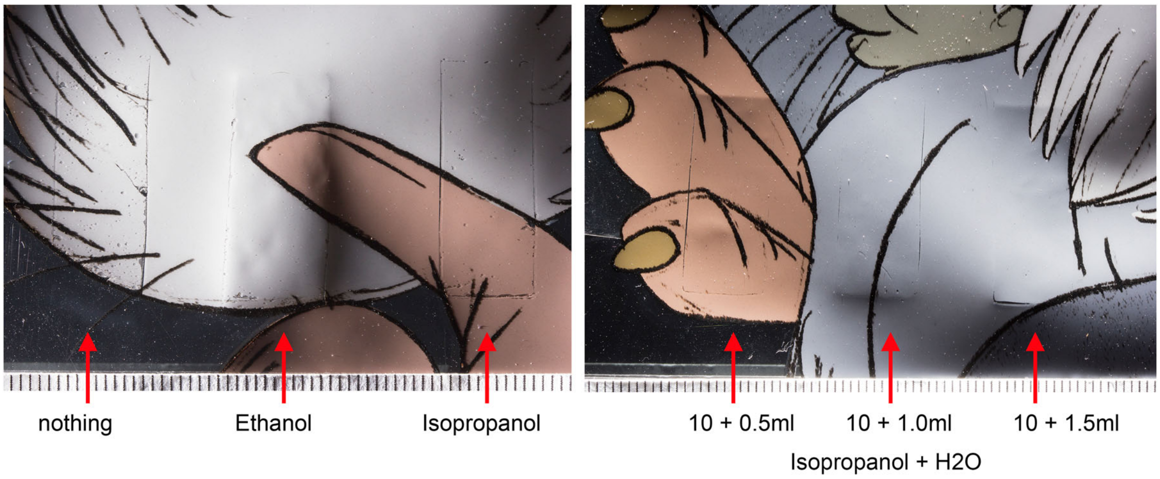


Figure 8. Cel 140. Tests at 71% RH, fluid application, and drying under pressure show visible sheet distortions using various solvents. ©Disney Enterprises, Inc.

afterwards between the paint and sheet, the sheet did not swell, and the paint showed no surface changes (Figure 8). Small pockets of air were mostly due to particle enclosures. The air pockets can be avoided by meticulously cleaning the paint, sheet, and tools used.

At 70% RH, the paint had a good flexibility and the best handling properties. At 50% RH, the paint was just flexible enough to bend without breaking. At 75% RH, the paint was too sticky to handle, and at 80% RH the paint was too soft to touch. At 70% RH, ethanol and isopropanol-water mixtures led to paint disintegration, where higher water content led to higher paint disintegration. All solvents tested created sheet distortions and ranked from most to least: ethanol > isopropanol-water mixtures > isopropanol (Figure 8). Sheet distortions were more pronounced with treatments at higher RH. The only case that did not lead to any visible sheet distortions was the utilization of the RH of the environment alone. The use of filter paper compared to adding solvent by brush did lead to visibly less sheet distortions and gave more control over handling, in that the paint film was supported during reattachment. Using the ultrasonic mister, the solvent mist could not reach the seam of attached to detached areas, even when adapting the mist outlet. Also, handling was limited, in that more than two hands would be needed to have control of the paint film. Drying under pressure led to visibly more pronounced sheet distortions compared to the same tests without pressure. From these tests, the potential of using the RH of the environment alone for paint reactivation in practice was evident. To achieve more consistent results, this approach was further developed.

Results

General approach to paint reattachment

From the tests, it proved best to manipulate the paint using elevated RH. Therefore, a walk-in environmental chamber large enough to fit a standalone humidifier,[7] worktable, and microscope was needed. At the WDARL, a walk-in chamber made from plastic tubing covered with plastic sheet was already in use to treat works of art on paper, so it was utilized for the paint treatment experiments (Figure 9).

For the treatment of animation cels, a specially designed workstation based upon approaches for reverse-glass paintings conservation was built (Magin 2002, 320). To permit simultaneous viewing of the front while treating the back, the cel was elevated onto a glass

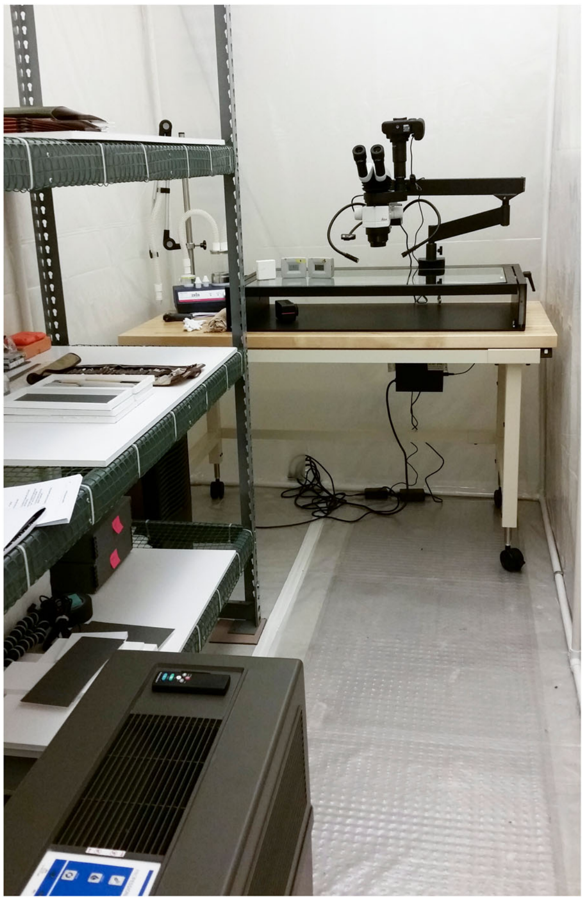


Figure 9. Walk-in environmental chamber. ©Disney Enterprises, Inc.

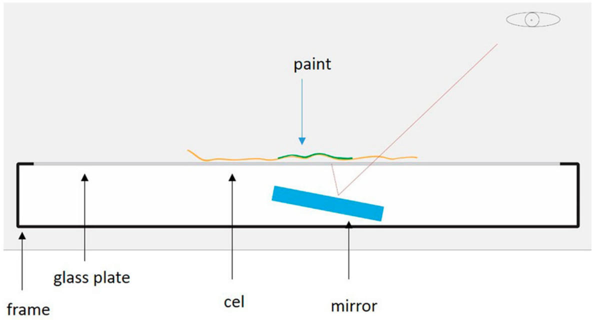


Figure 10. Specially constructed workstation.

plate and a mirror placed underneath (Figure 10). For treatment, the cel was placed face down and remained in this position until after treatment. All observations of the viewing side took place through the mirror. Illuminating the viewing side from under the glass plate helped produce a better mirror image. The mirror was tilted and moved into the right position at all times during treatment.

It was important to work in a nearly dust-free environment with clean and dust free tools, as any tiny particle between sheet and paint would remain visible due to non-attached areas around the dust particle. Thus, all paints were checked and cleaned of even microscopic particles using an insect needle. Also, every tool and aiding material was dusted before every single use with a compressed gas duster.[8] Sandbags were placed in strategic positions to keep the cel flat and as places on which to rest the wrist and steady the hand during treatment.

For paints from 1961 to 1985 on cellulose diacetate sheet the method developed for paint reattachment was divided into several steps:

(1) Pre-treatments (see sections on Case study treatment: *The Aristocats, 1970,* and Additional challenges).
(2) At 72% RH the cel to be treated was placed in the environmental chamber, face down onto the workstation, and given 1.5 h to reach equilibrium.[9] Once the surfaces to reattach were free of particulates and once the paint consistency was right, the air between paint and sheet was smoothed out using a silicone tip tool wrapped in Teflon® tape.[10]
(3) In the second step, humidity was raised to 75% RH. After equilibration, remaining bubbles were opened using a porcupine quill[11] and the air gently pushed out using a silicone tip tool.
(4) In the third step, humidity was raised to 80% RH for several hours or overnight, giving all smaller air bubbles time to settle. In this step, the cel remained untouched.
(5) Lastly, the RH was slowly lowered down to ambient levels. Only after equillibration to ambient RH, the cel could be turned around and observed from the viewing side.

This approach should not be taken as a recipe, but rather serve as a reference which needs to be modified for each cel, depending on the flexibility of the paint to be treated. While most paints had good working properties for reattachment at 71–72% RH, others needed 75% RH in order to reach similar properties. However, it would be advised to work with the lowest RH possible for a paint just flexible enough to reattach but not too flexible in order to cause the least amount of paint stretching.

For earlier paints from about 1945 to 1960, a paint reattachment method was developed similar to the one described for paints from 1961 to 1985. The main difference was the necessity of using a higher RH for the paint to reach a similar consistency at each treatment step, as these paints contain less binder and humectant. Another important difference to consider is the ink, which before 1960 was essentially thinned paints. Therefore, these inks react similarly to changes in RH as the paints. For this treatment, a technique was developed that kept the inked side at a lower RH, while increasing the RH on the painted side. This could be achieved by using a dew point generator,[12] creating a stable micro-environment for the inked side (Figure 11). The RH was set for the ink to not be sticky, and difference in RH minimized between the ink and paint sides of the cel.

A consistent, minimally invasive paint reattachment method for paints from 1937 to 1942 still needs more research. These paints present another challenge for method development as the paint composition, and thus its properties, are not as consistent as for the later paints. A considered case-by-case approach based on experience will be inevitable for these earliest cels.

Every paint reacts differently to the exact same changes in RH, depending on the amount of binder and humectant, the paint thickness, and presumably the storage history. Paint reattachment is about the right paint consistency at each step, which relies on the experimental knowledge and manual intelligence of the conservator.

Case study treatment: The Aristocats, *1970*

The Duchess cel from Walt Disney's animated feature *The Aristocats,* 1970 serves as an example that illustrates all treatment steps in detail. A 12 × 16 inch (30.5 × 40.6 cm) CDA sheet is the base for the ink and the paint. The paint is likely based on a typical recipe for later paints (section on Ink and paint characterization: composition – properties – damages). The paint is in poor condition and most of it is detached from the sheet, as seen in dark areas of raking and UV-induced luminescence images (Figure 12(a)). Also, it is obvious that the body of the cat is not aligned with the outlines, and the whole body is shifted (Figure 13(a)). This observation suggests that the paint had been detached as a whole, and partly reattached over time. The image also shows a previous attempt of conservation with a pressure sensitive matte finish tape being applied to cracks of the paint (Figure 14(a)).

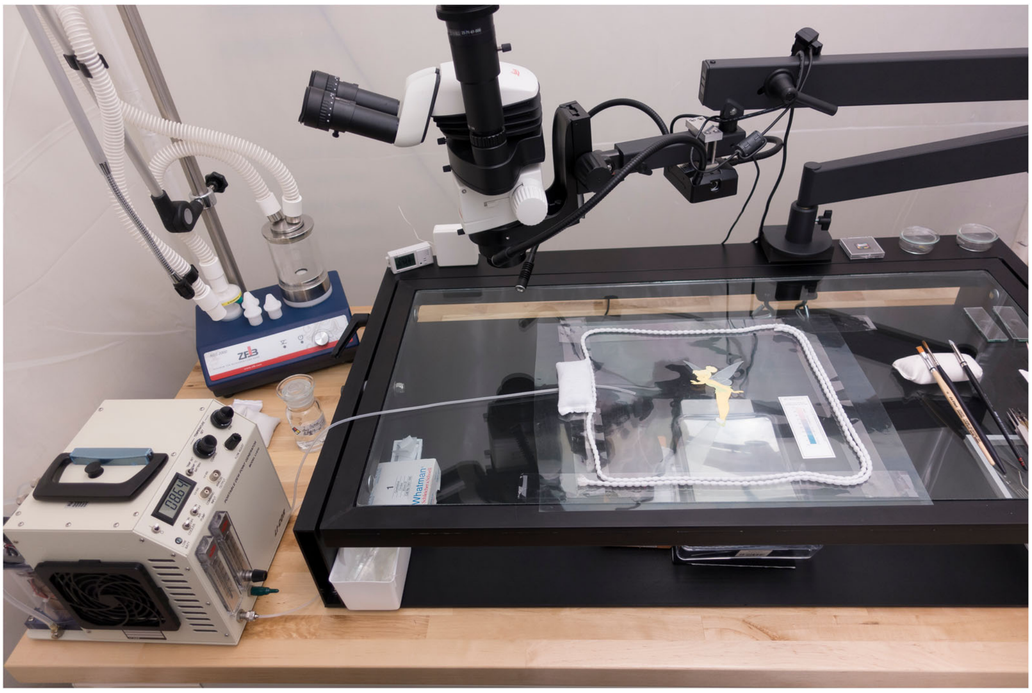


Figure 11. Dew point generator hose created an air flow with a set RH. Mylar strips were placed along the edges of and in overlap with the cel. String weights secured the Mylar strips in place. A humidity indicator card indicated the actual RH on the inked side. An air cushion was created that releases the excess pressure to all sides. ©Disney Enterprises, Inc.

(a) Before treatment (b) After treatment

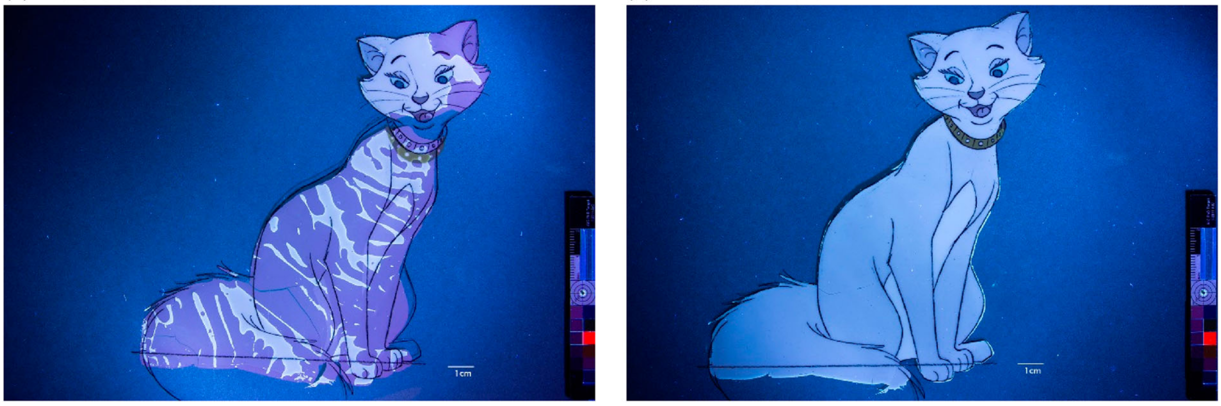


Figure 12. (a) and (b) UV-induced luminescence in the visible range, front. © Disney Enterprises, Inc.

(a) Before treatment (b) After treatment

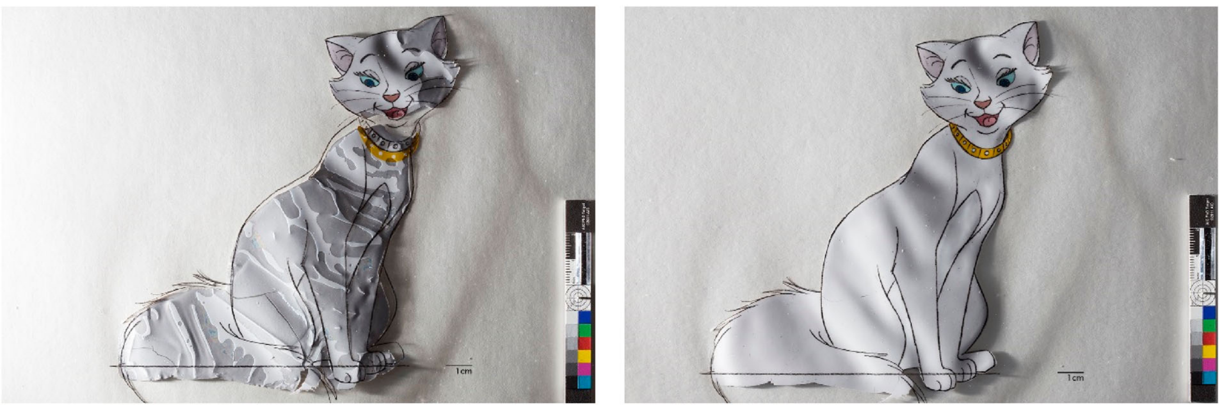


Figure 13. (a) and (b) Raking light, front. © Disney Enterprises, Inc.

(a) Before treatment (b) After treatment

Figure 14. (a) and (b) Raking light, back. © Disney Enterprises, Inc.

Step 0: Many treatments are not as straightforward as the general approach proposes and do require other steps to be taken beforehand. In this case, the paint had to be detached (as it had become stuck in the wrong position) and repositioned before it could be reattached. Also, the tape needed to be removed. For these steps, the cel was placed face down onto the workstation. At 72% RH, the pressure sensitive tape was removed using tweezers by slowly pulling at an acute angle. After the paint reached equilibrium, it could be detached from the sheet using a flat brush gently pushing between paint and sheet. During this process, because the paint film was quite large (ca. 10 × 20 cm), a cleaned and dusted filter paper[13] was slid underneath to support the free paint film and keep it from unwanted reattaching. Throughout this process, the paint remained flexible, and did not show any surface changes. If the paint was not flexible enough in this stage, it would not come off as a continuous paint film and would break. If the paint was too flexible for this treatment, it would stretch more, the brush would leave marks in the paint surface, and the paint would attach to the filter paper. After complete detachment of the cat's body, the painted side that would contact the sheet was checked for any dust or dirt particles, which might have embedded after years of the paint being detached. Every dust particle was taken off under the microscope using the sharp end of an insect needle. Realignment of the paint film was started with the support of the filter paper and fixing a few spots by gently pushing the paint down with a silicone tip tool.

Step 1: The cel was kept in position from the pre-treatment at 72% RH. Once the paint film was positioned, paint reattachment proceeded from the center moving outward in order to ensure a proper alignment. As the paint was smoothed down using a silicone tip tool wrapped in Teflon® tape, it looked reattached in those areas where the correct pressure was used. Pressures that were too low would lead to numerous air pockets, and high pressures would rip the paint. Smoothing rather than pushing was important for minimizing the occurence of air bubbles. Attention should be given to keeping channels open through which air can move out in order to avoid air bubbles. This process of paint reattachment is reversible; if needed, the paint could easily be detached again using a flat brush. In the case of the correct RH, the paint will look reattached with, perhaps, some minor irregularities that will disappear in the following steps. If a larger area was treated, the paint may stretch a bit. If the humidity for reattachment was too low, many air bubbles and enclosures remain. If the RH was too high, the paint will have creased and stretched significantly and will no longer align with the outlines. Also, the paint texture might be damaged or might be too sticky to work with. A difference of 1–2% RH makes a significant difference regarding the flexibility of the paint (Videos 2 and 3 in Supplemental Data).

Video still 2: Paint reattachment from viewing side. © Disney Enterprises, Inc.

Video still 3: Paint reattachment from working side. © Disney Enterprises, Inc.

Step 2: At 75% RH equilibrium, larger remaining bubbles were opened up using a porcupine quill, producing a small hole as an air outlet. Working from the sides towards the hole, the air was gently pushed out using a silicone tip tool and/or wooden tools. At this RH, much care was taken not to damage the paint's surface texture.

Step 3: At 82% RH, the paint was given time to settle overnight. In this step, the paint should neither be touched nor the cel moved as the paint will be in a highly viscous to almost fluid state. Small minor irregularities due to air cavities and enclosures will settle on their own. It is important to have no air bubbles left, as the paint will start detaching again from these spots.

Step 4: The RH was slowly lowered down to ambient levels. At this point, the cel could be turned around and the viewing side observed, finally not only with a mirror. After this treatment, the paint looks perfectly reattached (Figure 12(b), Figure 13(b), Figure 14(b)). It is apparent that the paint of the cat's body stretched a bit and now extends about 1 mm beyond the right outline.

Evaluation: Three years after this treatment, and after storing the cel among others in the climate-controlled conditions of the WDARL vaults, no changes could be observed.

Additional challenges

Many cels exhibit additional conservation challenges such as interleaving paper sticking to the back of the paint, and paint particles sticking to interleaving papers, to another sheet, or to other paints. For cels at the WDARL these conditions are mainly due to storage at any given point of a cels lifetime with a RH slightly too high for the paint's needs (Carta 2019, 109).

In general, interleaving paper sticking to the back of the paint was removed at about 70% RH by pulling the paper at an acute angle with fingers or tweezers. Remaining fibers could be reduced by gently rubbing or sliding a silicone tip tool over the surface. Paint particles sticking either to interleaving paper, to one another, or to the sheet could be detached using a brush, razor blade, or scalpel wrapped in Teflon® tape. The tool is selected depending on the adhesion to the paper, paint, or sheet and the shape of the paint particle. Risk factors for all procedures are tearing of the paint, changing the paint's surface texture, and/ or scratching the sheet. If the scalpel or razor blade is wrapped well with the Teflon® tape, the sheet will not be scratched.

Evaluation and discussion

In this study, treatment methods for detached paint of Walt Disney animation cels have been developed for paints from the mid-1940s to the mid-1980s on cellulose acetate sheets. Access to deaccessioned cels for the tests was invaluable for the development of a conservation treatment methodology. Even though the treatment method for paints from 1961 to 1985 is mainly described here in detail, treatments for earlier paints are based on a similar approach, utilizing relative humidity to change the paint's properties to reactivate the binder and reattach the paint. Paint properties are changed temporarily for the duration of their treatment, so paints will regain their original properties upon returning to previous RH conditions. Paint reactivation is the least invasive conservation treatment possible, as it is fully reversible and retreatable.

Nevertheless, utilizing humidity to reattach paint through reactivation of the binder poses some questions.

How stable is the treatment?

No changes could be observed on all test and case study cels three years after their treatments. These cels were placed back in their original locations within the climate-controlled storage vaults of the WDARL.

How strong is the paint adhesion?

The resistance of reattached areas to mechanical changes was imaged and visually assessed. A desiccator using saturated salt solutions in 10% RH steps was used to monitor and document the onset of detachment and cracking. Test results show that the paint adhesion of reattached areas starts to fail below 30% RH. This correlates with the paint properties as a function of relative humidity as described in the section on Paint properties as a function of relative humidity. These results suggest that reattached paints have similar adhesion compared to paints that have always been attached.

What are the effects on the cellulose acetate sheets?

Sheet distortions are influenced by the relative humidity, as seen in tests of paint properties as a function of relative humidity on a macro scale (Video 1 in Supplemental Data). During humidity treatment, sheet curling is observed to a greater extent with cels humidified above 80% RH. Equilibrated back to 50% RH the extent of sheet curling returns to the original state prior to treatment. This was confirmed by comparing before and after treatment images. Another possible effect on the cellulose acetate sheets is enhanced deacetylation of the cellulose acetate when kept at higher relative humidity during a one- to three-day treatment procedure. To investigate this, ion chromatography was used on two selected cels to measure the acetyl content before, during, and after humidity treatment, with each sheet sampled twice in the center and at a corner. The two cels were chosen for their visual state of degradation. Before the humidity treatment started, one cel from 1967 showed no visual degradation apart from sheet warping, whereas the other cel from 1940 exhibited an area of crystallization in the center and sheet warping along the edges. Results show that after three days of exposure in the humidity chamber, no increase in deacetylation could be detected in both cases. Therefore, exposure to 70–80% RH in the humidity chamber for three days did not enhance deacetylation of the cels, so can be considered safe.

There is a need to further investigate the long-term effects of this treatment. Furthermore, research is needed to develop a method achieving consistent results for paints from 1937 to 1942 on cellulose acetate as well as cellulose nitrate sheets. Paint composition and mechanical properties are not as consistent as the later paints, thus the earliest cels will require a case-by-case approach. Also, research into reattaching black paints of Walt Disney animation cels needs to be investigated, as they often use different binder and additive formulations, with some containing cellulose derivatives. Preliminary tests into reactivation of the cellulose derivative binder using humidity looked promising. Though this research is specific to Walt Disney animation cels, other animation cels with similar paint formulations could be treated using the same, or a similar, approach.

Conclusion

This paper reports on the outcomes of an in-depth study into alternative approaches in the interventive conservation of animation cels that allow original paint to be retained and not replaced. The methods developed for reattaching flaking paint of Walt Disney animation cels and similar paints take into consideration paint formulation by manipulating relative humidity to reactivate the binder, in a truly reversible and minimally invasive way. This allows the original paint to be saved and reattached without consolidants, creating an adhesion strength comparable to untreated paint. Critical to development of the procedure was the availability of original deaccessioned cels, and equipment for treating animation cels and other painted plastic sheets with the particular implications of being reverse painted. This study highlights the importance of the combined knowledge gained from archival documentation, a condition survey, analytical studies, and macro- to nano-scale tests, leading to the bigger picture, all informing the conservation treatment approach. Up to today, three years after finishing minimally invasive case study treatments, no changes in condition have been observed.

Notes

1. Degalan® PQ 611 often known as Plexigum® PQ 611 is an acrylic polymer based on iso-butyl methacrylate.
2. All dates referred to relate to the productions surveyed.
3. In the process of making an animated movie there were several purposes for which animation cels were produced. Production cel refers to cels which were actually used in the production of the animated work (Getty Research Institute n.d.).
4. The Xerox process equipment at the Walt Disney Ink & Paint Department spread over three rooms. In the first room, the animator's drawing was illuminated. The second room contained the camera, which exposed the drawing onto a coated aluminum plate, and the resulting image was then coated with toner. In the third room, the toner was transferred and fused to a sheet by exposure to fumes of trichloroethylene.
5. Shell OMS: mixture of aliphatic hydrocarbons with a boiling range 175–205°C.
6. ShellSol A100: C9-C10 aromatic hydrocarbon.
7. See List of equipment and tools.
8. A compressed gas duster should be used with caution as condensation can occur on the outside of the can. To dust the object a manual dust tool should be used, such as an air bulb commonly used to dust camera lenses.
9. Equilibrium is reached at a given relative humidity once the paint properties do not change any longer. Based on experimental knowledge it takes about 1.5 h for a gum arabic-based paint to reach equilibrium (See section on Paint properties as a function of relative humidity).
10. The silicone tip tool is wrapped in Teflon® tape (also known as polytetrafluoroethylene (PTFE) tape, thread seal tape, or plumber's tape) to avoid sticking of the paint to the tool and possible silicone residues on the cel.
11. A porcupine quill does not damage the sheet surface upon touching and can be sanded to a thin but sturdy tip, if necessary. All metal tools and needles will leave a mark upon touching the sheet surface, which becomes visible as a bump from the viewing side.
12. See List of equipment and tools.
13. A cleaned and dusted filter paper was choosen because it was found by experience to introduce the least amount of dust. Mylar instead carries too much static and thereby attracted more dust.

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List of equipment and tools

Item	Specifications	Supplier
Workstation	Custom designed workstation Consisting of a rectangular aluminum box with a glass plate inlaid on top, adjustable and able to pivot in both directions. The long sides of the aluminum box are open to allow access.	Hales Engineering Co.Inc. 18 Wood Rd Camarillo, CA 93010
Microscope	Leica M80 stereomicroscope with Ergo Tube 10°50° binocular, Documentation tube, Flexarm stand with table clamp and Leica LED5000 SLI	JH Technologies, Inc. http://www.jhtechnologies.com/
Humidifier	Nortec Evaporation Humidifier B500 Professional Information at: http://www.brune-humidifier.com/shop/humidifiers/humidifier-b-500-professional.html	Local nortec representative: KSR Associates LLC http://ksrassoc.com/
Hygrometer	Onset HOBO MX 1101 temp/RH logger	http://www.onsetcomp.com/products/data-loggers/mx1101
Dew Point Generator	LI-COR Portable Dew Point Generator Model LI-610	https://www.licor.com/env/products/gas_analysis/LI-610/
Light	Fiilex P100 LED light	photo supply
Mirror	Enlargement/ magnification mirror	drug store
Silicone tip tool	COLOUR SHAPER, Royal Sovereign Ltd UK; 2 Taper Point FIRM, 2 Flat Chisel FIRM	art supply
Insect needles and their holder	BioQuip or Ento Sphinx Insect Pins Stainless steel, 100 pieces No.000	entomology or surgical supply
Quill	Porcupine quill	Etsy
Micro Scissors	Microdissection spring scissors	surgical or aquatic supply
Plastic spatula	Spatula made out of plastic, sanded	art supply
Dust-removal tool	Falcon Dust-off Model DPSXL 12 Professional 12 oz Electronics compressed-gas Duster	office supply
Dust-removal tool	Giottos Rocket Blaster AA1900, Large, Black	photo supply
Thread seal tape / Teflon tape	Gaflon P.T.F.E. 12 m × 12 mm × 0.1 mm made in France	hardware store
Weights	String weights, sandbags, flexible magnetizable weights (finger of glove filled with iron powder)	conservation supply or home-made