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ANIMATION CELS: CONSERVATION AND STORAGE ISSUES

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ABSTRACT

An analytical survey was conducted of animation cels in the Walt Disney Animation Research Library (ARL) collection, made for animated films from 1929 to 2003, that addressed three main topics: (1) characterization of cel polymers and plasticizers; (2) assessment of cel degradation in storage; and (3) assessment of cel degradation and microenvironments in passe-partout mounts.

FTIR was helpful in differentiating the main polymer types: cellulose nitrate, cellulose diacetate, cellulose triacetate, and polyester. The majority of the cels were made from cellulose diacetate before 1981, and cellulose triacetate thereafter. Pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) identified a number of distinct plasticizer mixtures–primarily triphenyl phosphate mixed with phthalates–in the diacetate and triacetate cels. Estimates of the acetyl content by gas chromatography/mass spectrometry, which assessed the degree of substitution in the cellulose acetate cels, revealed that few cels showed evidence of hydrolysis. Levels of acetic acid vapor produced by cels in storage vaults at the ARL, as measured by A-D Strips, confirmed that few cels were at risk. Finally, the concentration of acetic acid vapor in passe-partout mounted cels for traveling exhibition, as measured by GC/MS and A-D Strips, was minimal.

Animation cels represent a unique and important cultural legacy of the 20th century. This study revealed that cellulose acetate cels have a range of compositions, which ultimately may affect their stability. Further research is needed to find optimum storage environments that reduce the rate of hydrolysis of the cellulose acetate without damaging the ink and paint layers.

1. BACKGROUND

Hand-drawn animation, which began as an art form in the early 20th century, was made possible by advances in the plastics industry. In traditional hand-drawn animation, each moment in time was captured onto a thin, transparent sheet of plastic called a cel. Characters or objects were meticulously drawn in ink onto the front of the cel; colors and details of the characters were then painted onto the verso. Once completed, each cel was placed face up on a painted background to position the character or object into a scene and photographed sequentially. Played back on a movie projector, the progression of photographs in a sequence created the illusion of motion. It took an average of 1440 photographs of individual animation cels to capture 1 min on film. The process required an enormous amount of time, effort, and resources to complete a full-length animated feature. Although animation today is almost entirely done on computers, a rich legacy of stories and beloved characters from our childhood was created.

Only a few plastics possessed physical properties suitable for use as animation cels. The plastic needed to be sturdy enough to hold paint layers, but pliable enough to manipulate it onto the animation pegs, which aligned the character in position for the camera frame. It also needed to be colorless and transparent, essentially disappearing on the screen, so that the characters were perceived to exist in the background environment. Cellulose nitrate was the first polymer used for cels, but its inherent flammability and tendency to yellow, wrinkle, and evolve corrosive nitric acid over time caused severe problems. Cellulose acetate, another cel polymer, was much less flammable, but was susceptible to photodegradation, hydrolysis (with the release of acetic acid), wrinkling, discoloring, and shrinking. Cels today are made from polyester (Mylar), which exhibits good mechanical and chemical stability, but because its polished surface is difficult to wet by traditional gum-based paints, synthetic paint media such as vinyl or acrylic are preferable.

Walt Disney recognized the historical value of artwork from his films, including elements that are not seen on screen; hence, early in the evolution of The Walt Disney Studios, he established a repository for the animation artwork in the basement of the Ink and Paint building on the studio lot called the "art morgue," after a term used in the newspaper business for a location where old files and notes were retained. All aspects of the animation process were retained and preserved there: painted animation cels and backgrounds, animation drawings, story sketches, layout drawings, character sculptures, and visual development paintings. It is a working collection regularly utilized as a source of inspiration and education for the animation staff. The collection currently comprises over 65 million pieces of animation artwork, mostly works on paper. It continues to grow with each production both in physical and, more recently, digital assets; approximately 10% of the collection consists of animation cels.

Given the growth of the Walt Disney Studios and the long history of the animation artwork collection, it should come as no surprise that, over the years, the storage location has changed several times, and along with it, the environmental conditions within storage. For instance, the original basement location of the Art Morgue had no special controls on the storage environment, and much of the collection was kept in metal filing cabinets. In 1989, the collection was relocated to air-conditioned storage areas in the Walt Disney Animation Research Library (ARL). Since 1999, the collection has been stored in vaults fitted with museum-standard security and HVAC systems, along with a staff dedicated to care for it. The environmental conditions are set to 62–65°F and 50% (+/– 2%) relative humidity. Cels are interleaved with 2 mil polyethylene sheets and kept in archival boxes. It is worth noting that exposure to light in every storage location has been limited, and that newer cels have spent proportionally more of their lifetime in environmentally controlled conditions.

The Image Permanence Institute has studied extensively the effects of storage on the useful lifetimes of acetate film, and established the IPI Storage Guide for Acetate Film with recommendations on temperature and relative humidity levels for the preservation of the material (Reilly 1993). The guide recommends reducing the temperature and relative humidity in storage environments to slow the rate of hydrolysis of acetate film. With some exceptions, the cel collection appears to be in remarkably good condition. The most commonly observed conservation concerns for cellulose acetate cels are buckling, discoloration, and off-gassing of acetic acid; therefore, the climate-controlled storage vaults at the ARL are helping slow down the rate of hydrolysis of the cels.

To learn more about the relationship between deterioration phenomena and composition, the Getty Conservation Institute and the Walt Disney ARL initiated a project in 2009 to study the plastic substrates of animation cels. Individual cels from various Disney productions were analyzed using multiple techniques to investigate three main areas: (1) characterization of cel polymers and plasticizers; (2) assessment of cel degradation in storage; and (3) assessment of cel degradation and microenvironment in passe-partout mounts.

2. ANALYTICAL METHODS

An important component of this research was to better understand the range in composition of the cels in the ARL collection versus production date. This involved measuring several key parameters using various noninvasive and invasive analytical techniques and procedures: polymer type, plasticizer content, plasticizer distribution, and the degree of acetylation (Giachet et al. 2014; Truffa Giachet et al. 2014).

An A2 Technologies portable FTIR equipped with a diamond/zinc selenide attenuated total reflectance probe (FTIR-ATR) was used for noninvasive identification of the polymers in 110 cels dating from 1929 to 1988. The ATR probe was placed directly onto the cels during measurement. Analysis of samples taken from a second set of 75 cels, dating from 1934 to 2003, was performed in transmission mode using a Bruker Hyperion 3000 FTIR microscope with a liquid-cooled MCT detector and Opus software version 6.5. Analysis was performed over a spectral range of 600–4000 cm^{-1}, using a wave number resolution of 4 cm^{-1} and 64 scan accumulations. The sample preparation consisted of flattening the cel fragments on a diamond window using a metal roller.

Invasive tests were conducted on samples from 75 cellulose acetate cels dating from 1931 to 2003. Plasticizers were identified using pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS). Small discs of cels (~0.5 mm in diameter) were pyrolyzed at 550°C using a Frontier Laboratories 3030 microfurnace pyrolyzer, and analyzed with an Agilent 5975C inert MSD/7890A GC/MS on a 30 M × 0.25 mm × 0.25 μm DB-5MS UI column with a Frontier Laboratories Vent-Free Adaptor. The GC method was 40°C for 2 min, 20°C min^{-1} to 320°C; helium carrier at 1 mL · min^{-1}. Plasticizers were identified on the basis of their mass spectra, and peak area percentages were calculated for each. Only plasticizers present above 5 area percent were reported. Plasticizer content was measured by extracting 1 mg pieces of cels in a 1:1 mixture of ethanol and hexane, and weighing the solid polymer residue after decanting drying.

The degree of acetylation of the cellulose acetate polymer was measured by aminolysis using pyrrolidone, which converts the acetyl groups to acetylpyrrolidine. The polymer residue remaining after extracting the cels with 1:1 ethanol:hexane was used in this test instead of the cels, since the contribution of plasticizers to the total weight of the cels would result in a systematic measurement error. In this procedure, 200 μL of pyrrolidine were added to the polymer residue (from 0.3 to 0.9 mg) in a crimp-top vial. The vial was heated at 80°C for 18 hours, with vortex mixing after 3 hours and again after 18 hours. After cooling, the solutions were analyzed on an Agilent 6890/5973 inert GC/MS with a Frontier Laboratories Ultra ALLOY 1 capillary column (30 m × 0.25 mm × 0.5 μm) and Vent-Free Adaptor. The GC method was: 80°C for 1 min, 20°C · min^{-1} to 195°C, 120°C · min^{-1}. to 300°C and 2.3 min isothermal; helium at 0.4 m · s^{-1}; split injection at 280°C with a 50:1 split ratio. The acetyl content of the samples was evaluated using a linear calibration curve forced through zero from standard solutions of acetylpyrrolidine ranging from 1000 to 10,000 ppm in pyrrolidine. The percent acetyl content is calculated using equation 1:

(1) % acetyl = 38.02 × (ppm acetylpyrrolidine) × (mL pyrrolidine) / (μg cellulose acetate)

The degree of substitution expresses how many of the three hydroxyl groups on the cellulose ring are acetylated. The relationship between % acetyl and the degree of substitution is shown in equation 2 (Loo et al. 2012):

(2) DS = (3.86 × % acetyl) / (102.4 − % acetyl)

A small number of cellulose acetate production cels displayed in passe-partout mounts for a 2006 travelling exhibit were examined in this study (table 1). A VICI Pressure-Lok precision analytical syringe inserted into the sealed package was used to remove 2.5 mL of the enclosed air space, which was then analyzed for acetic acid using an Agilent 6890/5973 inert GC/MS on a 20 M × 0.18 mm × 1.0 μm DB-624 column with Vent-Free Adaptor. The GC method was: 30°C for 1 min, then 20°C min^{-1} to 90°C; helium at 59 cm s^{-1}; and splitless injection at 150°C with 60 s purge-off time.

Art-Sorb from selected 2006 passe-partout mounts (samples 1, 3, and 4 from table 1) was extracted with ethanol and tested for acetic acid using an Agilent 689ON/5973 GC/MS on a 25 M × 0.2 mm × 0.2μm INNOWAX column with Vent-Free Adaptor. The oven program was 80°C for 2 min, then 10°C · min^{-1} to 260°C; helium set to 44 cm · s^{-1}; and splitless injection at 260°C with 60 s purge-off time.

Table 1. Animation Cels in Passe-Partout Mounts from 2006

1. Cinderella cel setup: Mice-making dress
2. Sleeping Beauty cel: Sleeping Beauty in the forest with animals
3. The Little Mermaid cel setup: Ariel and Eric
4. Alice in Wonderland cel setup: Mad Hatter and Teacup
5. Sleeping Beauty cel setup: Squirrel in forest
6. Alice in Wonderland cel: Tweedle Dee and Tweedle Dum
7. Alice in Wonderland cel: Cheshire Cat

Table 2. Plasticizers Identified in Cellulose Acetate Animation Cels

Plasticizer	CAS Number	Abbreviation
Dimethyl phthalate	131-11-3	DMP
2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	6846-50-0	TXIB
Diethyl phthalate	84-66-2	DEP
Methyl carbethoxymethyl phthalate	85-71-2	MCMP
Ethyl carbethoxymethyl phthalate	84-72-0	ECMP
Dibutyl phthalate	84-74-2	DBP
Bis(2-methoxyethyl) phthalate	117-82-8	DMEP
Triphenyl phosphate	115-86-6	TPP

3. TEST RESULTS FOR CELS IN ARL STORAGE VAULTS

Table 2 lists information about the plasticizers detected in the cels by Py-GC/MS. The plasticizer content of cellulose diacetate cels ranged from 12 to 21%, whereas for cellulose triacetate the range was from 8 to 14%. These results show that plasticizer represents a significant proportion of cellulose acetate cels.

Tables 3 and 4 list the plasticizer compositions of cels made from cellulose diacetate and cellulose triacetate, respectively. It was discovered that multiple formulations of plasticizers were used in the cels,

Table 3. Average Plasticizer Compositions for Cellulose Diacetate Cels

		Peak Area Percentages						
Production Date(s)	Plasticizer Group	TPP	DEP	MCMP	TXIB	DMEP	ECMP	DMP
1937	A		91					7
1940	B		39	57				
1949	C	56	28				11	
1940–1981	D	55	43					
1967–1974	E	47	13		35		5	
1970	F	50				39		6

Note: The numbers of cels tested by Py-GC/MS within each of the plasticizer groups are: A (1), B (2), C (1), D (33), E (6), F (2).

Table 4. Average Plasticizer Compositions for Cellulose Triacetate Cels

		Peak Area Percentages			
Production Dates	Plasticizer Group	TPP	DMP	DBP	DMEP
1983–2003	G	71	27		
1995–2001	H	53		47	
1985–1986	I	88		5	6
1994–2000	J	88			11
1989–2002	K	97			

Note: The numbers of cels tested by Py-GC/MS within each of the plasticizer groups are: G (14), H (3), I (5), J (3), K (5).

and moreover that some formulations were more common than others. For instance, in the CDA cels, the most common formulation was triphenyl phosphate with diethyl phthalate, whereas in the CTA cels the most common formulation was triphenyl phosphate mixed with dimethyl phthalate. Triphenyl phosphate functions in cels both as a plasticizer and a flame retardant. The earliest CDA cels tested contained no TPP, whereas TPP was the sole plasticizer in some of the more recent CTA cels. In all, six groupings of plasticizer composition were identified in the cellulose diacetate cels (table 3), and five groupings of plasticizer composition were identified in the cellulose triacetate cels (table 4). The variation in plasticizer formulation may be due to the material being sourced from different commercial manufacturers, as well as the experimental process in the cellulose acetate production, considering that each manufacturer may have attempted to perfect their own formulations.

The results listed in tables 5, 6, and 7 show the number of cels tested from each production, their corresponding polymer type, and plasticizer group. The FTIR analyses revealed a number of important

Table 5. Polymer Types and Plasticizer Groups for Cels from 1929 to 1942

Title	Production Date	Plasticizer Group (# of cels)	# of CN Cels	# of CDA Cels
The Skeleton Dance	1929	—		2
Barnyard Olympics	1932	—	20	
Flowers and Trees	1932	—		1
King Neptune	1932	—	3	
Two Gun Mickey	1934	—		1
Three Little Wolves	1936	—		1
Snow White	1937	A (1)	13	2
Fantasia	1940	B (2)	3	14
Pinocchio	1940	D (1)		2
Dumbo	1941	—		2
Bambi	1942	D	1	1

Note: Polymer types were identified by bench-top and/or portable FTIR instruments, and plasticizer groups for CDA and CTA cels by Py-GC/MS. Comparatively, more cels were tested by FTIR than by Py-GC/MS; thus, where no number appears in parentheses after the group letter in the plasticizer group column for a production, the same number of cels were analyzed by both bench-top FTIR and Py-GC/MS. When a number is listed after the group letter for a production, the number signifies the number of cels that were analyzed by Py-GC/MS.

Table 6. Plasticizer Groups for Cellulose Diacetate Cels from 1943 to 1981

Title	Production Date	Plasticizer Group (# of cels)	# of CDA Cels
Saludos Amigos	1943	—	1
Three Caballeros	1944	—	4
Song of the South	1946	D	1
Adventures of Ichabod and Mr. Toad	1949	C	1
Cinderella	1950	D	2
The Brave Engineer	1950	—	2
Alice in Wonderland	1951	D (2)	33
Peter Pan	1953	D	1

(Continued)

Table 6. Plasticizer Groups for Cellulose Diacetate Cels from 1943 to 1981—*(continued)*

Title	**Production Date**	**Plasticizer Group (# of cels)**	**# of CDA Cels**
Lady and the Tramp	1955	D	2
The Sleeping Beauty	1959	D	2
101 Dalmatians	1961	D	2
The Sword in the Stone	1963	D	2
Mary Poppins	1964	D	2
The Jungle Book	1967	D, E (1, 3)	4
Winnie the Pooh and the Blustery Day	1968	E	1
The Aristocats	1970	F	2
Bedknobs and Broomsticks	1971	D	2
Robin Hood	1973	D	3
Winnie the Pooh and Tigger Too	1974	D, E (1, 1)	2
Pete's Dragon	1977	D	2
The Rescuers	1977	D	2
The Fox and the Hound	1981	D	4

Note: See note given for table 5.

Table 7. Polymer Types and Plasticizer Groups in Cels from 1983 to 2003

Title	**Production Date**	**Plasticizer Group (# of cels)**	**# of CTA Cels**	**# of PE Cels**
Mickey's Christmas Carol	1983	G	2	
The Black Cauldron	1985	G, I (1, 2)	5	2
The Great Mouse Detective	1986	I	3	
Oliver and Company	1988	G	2	
Who Framed Roger Rabbit	1988	—	2	10
The Little Mermaid	1989	G, K (1, 1)	2	
The Prince and the Pauper	1990	G	2	
The Rescuers Down Under	1990	G	2	
Beauty and the Beast	1991	G	1	
Aladdin	1992	G	1	
The Lion King	1994	J	1	
Pocahontas	1995	H, K (1, 1)	2	
The Hunchback of Notre Dame	1996	K	1	
Hercules	1997	J	1	
Mulan	1998	G	1	
Tarzan	1999	K	1	
The Emperor's New Groove	2000	H	1	
Fantasia 2000	2000	J	1	
Atlantis	2001	H	1	
Lilo and Stich	2002	K	1	
Brother Bear	2003	G	1	

Note: See note given for table 5.

findings. Four types of polymer were identified in the cels: cellulose nitrate (CN), cellulose acetate (CA) in the form of cellulose diacetate (CDA) and cellulose triacetate (CTA), and polyester (PE). CN was identified only in films produced between 1932 and 1942 (table 5), yet CDA was identified in some of these productions, even as far back as 1929. This runs counter to the prevailing assumption that CN was the only polymer used in cels until the 1940s (Saracino 2006). Next, in productions from 1943 to 1983, cellulose diacetate was the only polymer used (table 6). Cellulose triacetate was identified in productions dating from 1986 to 2003 only (table 7). Some polyester cels were used in two productions: *The Black Cauldron* and *Who Framed Roger Rabbit*. It should be noted that all cels in the ARL collection for productions dating after *The Little Mermaid* (1989) are, in fact, replicas of original computer animation artwork that were made for internal usage; thus, because production date was shown to be insufficient for determining polymer type, analysis is needed for accurate identification.

The degree of substitution results ranged from 2.0 to 2.6 for CDA cels (35–41% acetyl), and 2.8–3.0 for CTA cels (43–45% acetyl). It is encouraging that the CDA cels, which as the oldest in the collection are the ones that have spent proportionally less time in ideal storage conditions, still remain in the diacetate form. The wider variance of acetyl content in the CDA cels may be due to the effects of hydrolysis, but also from variation in the polymer manufacturers' original formulations and manufacturing technique. CDA is produced by making CTA which has a degree of substitution of 3, then partially hydrolyzing it to form CDA. Considering the number of parameters that would affect the rate of hydrolysis, such as pH and water content, this process may have been difficult to control carefully.

It was evident that the GC/MS test method, which was developed for measuring the acetyl content of wood fibers, worked remarkably well on the microsamples of cellulose acetate polymer residue obtained from solvent extraction of plasticizers in the cels. The method was found to be simple, rapid and accurate (Truffa Giachet 2014).

4. ASSESSMENT OF CEL DEGRADATION IN STORAGE

Of the many indicators of cellulose acetate degradation, perhaps the most noticeable in cel storage cases is the odor of acetic acid, formed by hydrolysis and off-gassing. A-D strips, developed by The Image Permanence Institute (IPI), are a reliable tool for identifying so-called Vinegar Syndrome in cellulose acetate film and in other forms of cellulose acetate (Image Permanence Institute 2001). A-D strips turn from blue to green to yellow with increased concentration of acetic acid. Depending on the environmental conditions, a strip placed directly on a CA object will change color within a certain period of time if acid is detected. A-D strips measuring 1–2 ppm indicate some degradation of the object has occurred, so the object may require closer monitoring. Objects giving measurements of 3–5 ppm are at a higher risk of vinegar syndrome, and may be close to the autocatalytic point at which the degradation process accelerates exponentially (Image Permanence Institute 2001).

To examine the effects of storage environment on the cels, A-D strips were used to monitor cels in storage vaults at the Walt Disney Animation Research Library. These were deployed in eight locations in four different storage vaults. These were placed directly on CA cels of varying age (1940–1988) that exhibited varying degrees of warping and discoloration. After 8 hours, all the strips appeared unchanged except for the strip placed on a cel from *Bambi* (1942), which showed a slight color change toward green. After an additional period of 88 hours (96 hours in total), the strip on the *Bambi* cel measured an acetic acid level of 1–2 ppm. In addition, three samples from 1950, 1959, and 1968 each showed a very minor shift in color (measuring <0.5 ppm). After a final period of 240 hours (336 hours/2 weeks in total), the strip on the *Bambi* cel measured an acetic acid level of 3–5 ppm. In addition, the three samples from 1950, 1959, and 1968 each shifted slightly more toward green to a level around 0.5 ppm.

5. ASSESSMENT OF CEL DEGRADATION AND MICROENVIRONMENT IN PASSE-PARTOUT MOUNTS

Passe-partout mounts, typically used for works on paper to produce a microclimate for the artwork inside of a mat package, are used routinely at the ARL for displaying cels on loan to museum exhibits.

The mounting process starts with hinging the artwork as desired, generally with Japanese tissue hinges attached using methyl cellulose or wheat starch paste, onto 8-ply acid free mat board. On the verso of the mat board, a sheet of Art-Sorb is applied with 3M ATG 987 Adhesive Transfer Tape. A Sud-Chemie Performance Packaging humidity indicator card is also adhered to a visible corner of the Art-Sorb. A sheet of .003 mil polyester is cut to fix the size of the mat board. The passe-partout package is then assembled placing the layers one by one face down on each other starting with the UV acrylic (Plexiglas), then the matted artwork with the Art-Sorb backing, followed by a sheet of polyester. The layers are sandwiched together using Scotch 845 Book Tape. The tape attaches to the front edge of the acrylic glass and continues along the side of the packet taking in all the layers wrapping around to the polyester sheet on the back. A bone folder is used to press out all air bubbles along the tape to create as airtight of a seal as possible. The passe-partout package is then placed in a frame with an archival foam core backer. A small window is cut out of the foam core to facilitate reading the humidity indicator card. The color changes of the humidity indicator card are recorded periodically. Figure 1 shows the layout of the passe-partout packages.

In 2006, the ARL loaned production cels to an exhibit entitled *Walt Disney: Il Etait une Fois* (*Walt Disney: Once Upon a Time),* which compared Walt Disney animation artwork to classical European artwork. The passe-partout mounted cels travelled to the first two venues of the exhibition, the Grand Palais, Paris, and the Musee des Beaux Arts, Montreal, before being removed from the tour. On returning

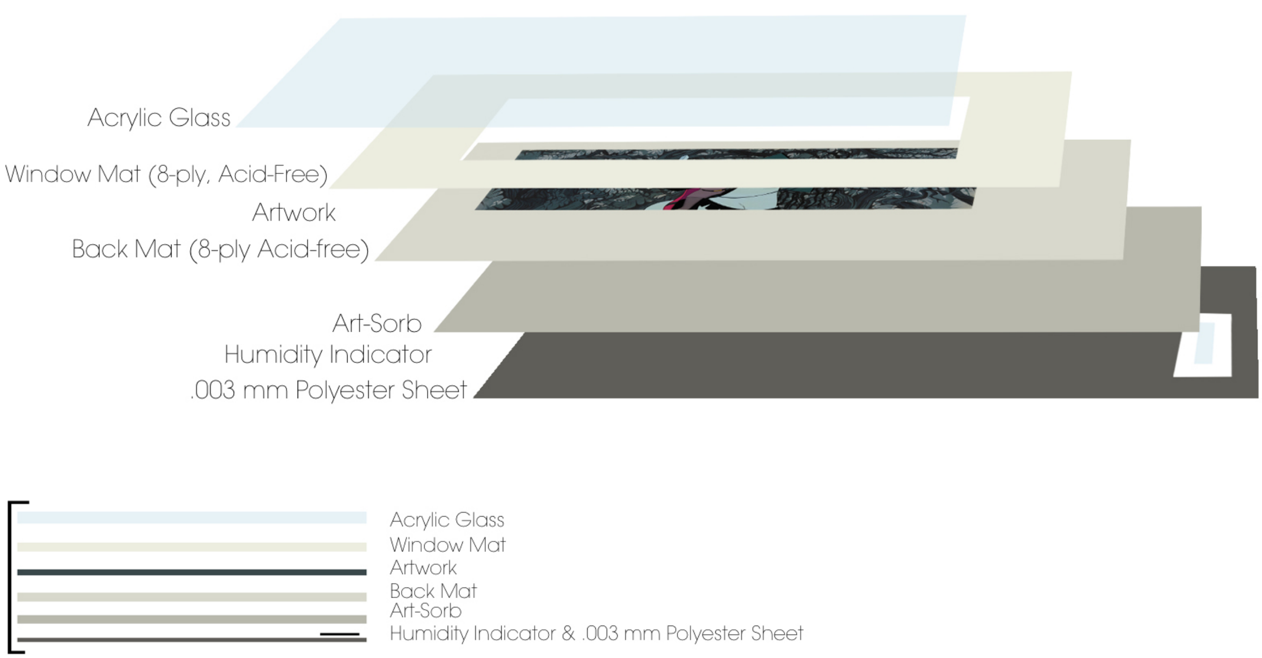

Fig.1. Schematic of passe-partout packaging for animation cels (Courtesy of Kristen McCormick)

to the ARL, most of the cels were unframed and reintegrated into the collection; however, it was noticed that paints on a few cels exhibited delamination and microcracking, so it was decided to keep these cels in their passe-partout mounts for eventual scientific investigation. In this study, the passe-partout packages for each of the damaged cels was investigated to test for acetic acid in the entrapped air, and to determine if acetic acid may have been adsorbed by the Art-Sorb.

All of the tests showed minimal amounts of acetic acid present in the passe-partout packages from 2006. The color of A-D strips (placed within the passe-partout packages in 2014, then resealed and observed for 30 days) remained unchanged in all the packages throughout the observation period. In GC/MS analysis of the entrapped air in each passe-partout mount, the concentration of acetic acid present was well below 0.8 ppm (estimated to be < 0.1), which is consistent with the A-D strip results. Moreover, no acetic acid was detected in the ethanol extracts of the Art-Sorb from the CA cel mounts; however, it is interesting that DMP and DEP plasticizers were detected in the Art-Sorb from the Cinderella cel mount, and camphor plasticizer was detected in the Art-Sorb from a CN cel from *Snow White and the Seven Dwarfs* (1937). These results show that Art-Sorb is capable of removing vapor from certain plasticizers from storage environments. Over time, this may affect the behavior of the enclosed plastic object (Richardson et al. 2014; Shashoua et al. 2014).

6. CONCLUSIONS

The results of this study illustrate the value of multiple analytical techniques for characterizing the four polymers used in cels and their additives. Noninvasive FTIR is a good technique for in situ identification of polymer types, and detailed information about plasticizers is obtained by Py-GC/MS. Because it is possible that the rate of hydrolysis may be affected by the plasticizer composition, especially for cels that lack TPP (Tsang et al. 2009), plasticizer identification is useful. The GC/MS method for measuring acetyl content showed no evidence of advanced hydrolysis in the cels.

Although the current storage environment employed at the Animation Research Library is beneficial to the cel collection, A-D strips revealed slight off-gassing of acetic acid from one of the oldest cels tested. A broader survey with A-D strips would be needed to identify other cels at increased risk of developing vinegar syndrome and to establish an assessment of the state of the collection. Although all cels inevitably are moving toward vinegar syndrome, a small subset of the collection is likely at higher risk; therefore, identification and subsequent isolation of those cels would be desirable to prevent accidental acceleration of hydrolysis in lower risk cels stored in close proximity.

No evidence was found, using A-D strips and GC/MS analysis of gas samples from passe-partout mounts made in 2006, that the mounts enhanced the degree of hydrolysis of the enclosed cels; therefore, the mounts do not appear to have contributed to the observed delamination and cracking of cels' paints. To better understand the risk factors contributing to degradation of animation cels while on loan, however, additional study needs to be conducted on the packing methods and orientation of the framed artworks within the crates, as well as changes in microenvironment during transit.

The challenge for preventive conservation of animation cel collections is that storage temperatures and relative humidity levels which increase the useful lifetime of the cellulose acetate sheets may negatively impact the inks and paints by causing cracking and delamination. Finding ideal environments for the mixed media of animation cels will require extensive additional studies, especially developing a thorough understanding of the mechanical response of paint layers and their plastic supports to changes in temperature and relative humidity. As caretakers of this unique 20th century art form, such research is essential if we hope to preserve animation cels for future generations.

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