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Cellulose Acetate Lamination: A Literature Review and Survey of Paper-Based Collections in the United States

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Abstract: Cellulose acetate (CA) lamination, a technique to strengthen documents by sealing them between sheets of thermoplastic film, was widespread from the 1930s to the 1990s. Its use gradually stopped in the 1980s amid concerns about the physical and chemical instability of the laminate and the degradation risks posed to the treated document. Despite concerns about CA lamination, no coordinated effort has taken place to establish the various materials and techniques used in cellulose acetate laminations or to determine the number and present condition of CA laminated documents in US collections. In this paper, we review the chemistry and methods used in CA lamination. We then report results of a survey of 52 US institutions with significant laminated collections. We find that at least 2.9 million laminated documents exist in US collections, and most of those documents are observed to be in stable condition. A majority of the institutions used cellulose diacetate (CDA) as the laminating film and as few as 0.6% CDA laminated

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documents have been delaminated. The results should aid institutions in determining the cost benefit in the management of these significant collections.

Keywords: Cellulose acetate lamination, Barrow lamination, delamination, literature survey, peer survey, conservation treatments

1 Introduction

1.1 Materials and methods of CA lamination

In their book "Bookbinding and the Conservation of Books: A Dictionary of Descriptive Terminology," Etherington and Roberts define lamination as:

> A method of protecting and preserving embrittled or otherwise weak papers, maps, etc., by placing them between sheets of thin, transparent thermoplastic material, which, when subjected to heat and pressure, with or without an adhesive, seals the paper in and protects it by making it more or less impervious to atmospheric conditions. It also increases its effective strength (Etherington and Roberts 2011).

It is well known that books and paper made from wood pulp suffer from degradation. In fact, paper from wood pulp with acidic sizing degraded with age to such an extent that by the beginning of the twentieth century, book binders, restorers and conservators were worried that books printed then might not last to the end of the century (Brooks 1947). A consequence of paper degradation is that the book pages become brittle and fall apart with handling. Numerous materials and methods of treatment were used to address this brittleness as shown in Table 1. An early treatment was silking, the application of silk with paste to either face of a page to add strength. However, cellulose acetate lamination replaced silking in many institutions due to the volume of documents that needed to be treated (deValinger 1965). Cellulose acetate lamination was touted as a process that could strengthen brittle paper, and, because of its solubility in acetone, was a reversible treatment. It was also a much faster treatment method, and the lamination of paper was widespread from the 1930s to the 1990s. While the treatment was developed and used primarily in the United States, it was also adopted by institutions in France, the Netherlands (Bolsée 1950), England (Barrow 1970), India (Kathpalia 1977) and Brazil (Christo and Berwanger 2001), and several other countries, persisting for shorter or longer periods.

The practice of CA lamination appears to date to a 1928 study by the National Bureau of Standards (NBS), now the National Institute for Standards and Technology (NIST), and the Library of Congress (LC) of the United States,

Table 1: Preservation methods contemporary with cellulose acetate lamination.

Lamination type	Method			
	Film	Bonding agent	Lining paper	Application process
Ademco[a]	Cellulose acetate film	Synthetic resin adhesive	None	Heat and Pressure
Dipping/Spraying[b]	Cellulose acetate	None	None	Spraying or Dipping
Cellulose Nitrate – Film[c]	Cellulose nitrate	Solvent: amyl acetate	None	Dissolved and painted on
Goel Process[d]	Cellulose acetate	Solvent: acetone	Japanese tissue paper	Solvent applied to CA film through tissue paper and hand pressed onto the document
Mipofolie Process[e]	Polyvinyl chloride	Pressure-sensitive adhesive	None	Pressure
Morane/Ultraphan Process[e]	Cellulose di- or tri-acetate	heat-sensitive adhesive	None	80°C heat and pressure
Postlip Duplex Laminating Tissue[e]	Tissue paper	Polyvinyl acetate with magnesium acetate	Japanese tissue paper	Moderate pressure for 60 seconds and 80°C heat
Polythene[a]	Polythene	None	None	Heat and pressure
Silking[f]	Open-weave silk	Starch paste or dextrin	None	Silk is applied over paste
Sundex[a]	Glassine – a glazed paper	Starch or soluble cellulose derivative	None	Adhesive is applied at 70°C

[a]Darlington (1955), [b]Scribner (1940), [c]Edge (1989b), [d]Goel (1953), [e]Werner (1964), [f]Marwick (1964).

which explored CA along with cellophane and cellulose nitrate films to strengthen brittle newspaper (Gear 1965; Scribner 1934). Cellulose acetate refers to cellulose that has undergone some degree of acetylation. The mechanism of the reaction is shown in Figure 1 where some hydroxyl groups have been replaced with acetate groups. Similarly, cellulose nitrate contains nitrate groups. Thus, while both cellulose nitrate and CA can be described as "semi-synthetic" polymers made from cellulose, the CA polymer increasingly replaced cellulose nitrate in films to overcome the instability and flammability of the cellulose nitrate used in many industries in the latter half of the nineteenth century and the early twentieth century (Kenyon 1951).

The general recipe of cellulose acetate is cellulose, 30 to 40 parts glacial acetic acid (solvent), 20 to 30 parts acetic anhydride (source of acetyl

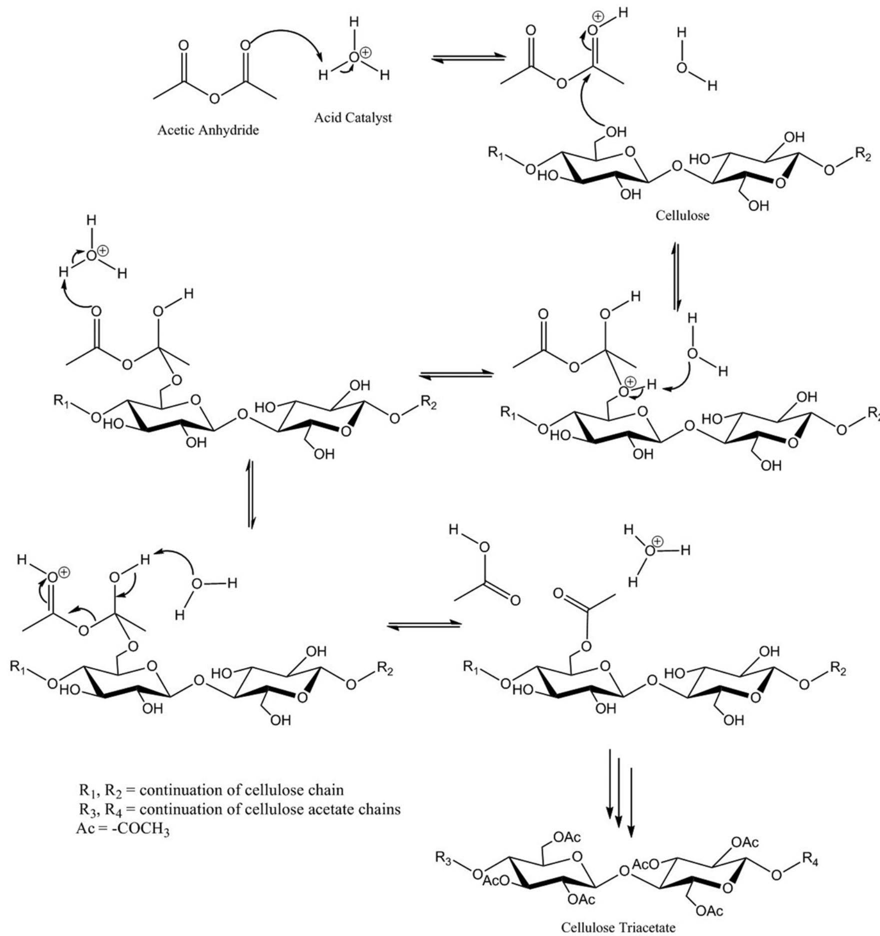

Figure 1: A simplified schematic diagram of the cellulose acetate synthesis mechanism. The triple arrow signifies several steps.

substituent), and 1 to 2 parts concentrated sulphuric acid (catalyst) (Stannett 1950). Many patents have been filed, however, on variations in the synthesis and processing of cellulose acetate including variations in time, temperature, catalyst and the exact composition of the acetylating bath (Hofmann and Reid 1929).

In the CA molecule, the number of acetyl groups per monomer unit (known as degree of substitution (DS)) can vary. Straightforward acetylation produces cellulose triacetate (CTA, Figure 1) which has a DS of ~2.7 or greater (Edge et al. 1988). Hence, the first CA to be produced was CTA (Schutzenberger 1865). Because it was soluble in only the harshest solvents (e.g. chloroform and dichloromethane), CTA was not immediately useful in industry (Dreyfus 1939). In 1904/05 it was independently discovered in Germany and the USA (Miles 1906; Rustemeyer 2004; Vaupel 2005) that water can be added to CTA during manufacture to remove acetyl groups in a step known as hydrolyzing. This yields cellulose diacetate (CDA Figure 2) with DS 2.7-2.2 (Hofmann and Reid 1929). The polydispersity (PD) or the range in the length of CDA molecules in a particular batch varies based on cellulose source (Stannett 1950). Cotton linters were the most common source of cellulose in early manufacturing with PDs ranging from 150,000–500,000 amu (Stannett 1950). Soluble in more solvents including acetone (Rustemeyer 2004), CDA was a commercially viable film, beginning with Bayer's "Cellit" product in 1905 (Vaupel 2005). This increased solubility allows for the reversal of CDA lamination of documents as described below.

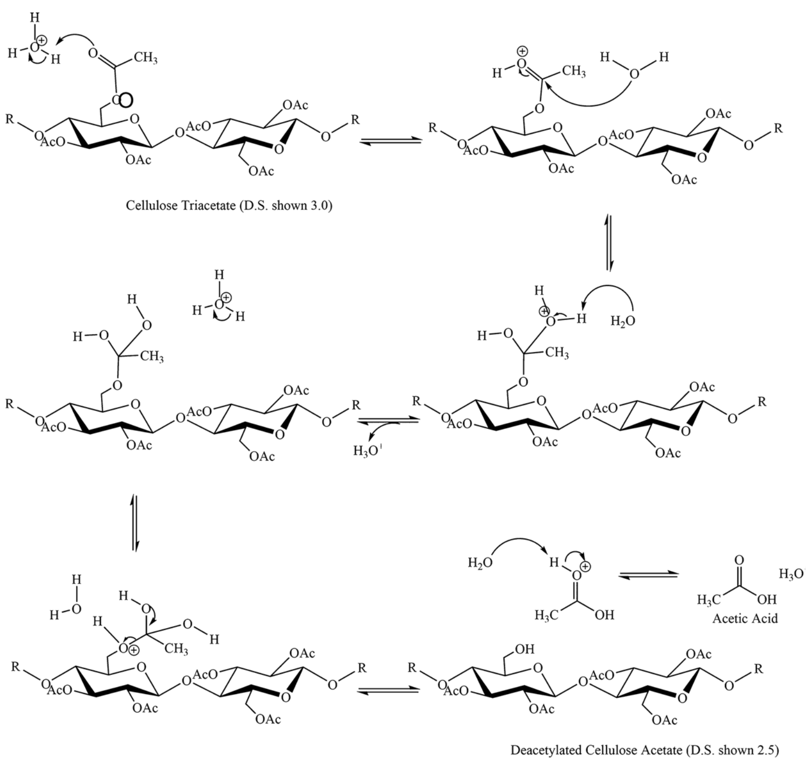

Figure 2: Acid-catalyzed deacetylation of cellulose triacetate.

The manufacture of CDA films is accomplished by dissolving the cellulose acetate fibres in a solvent such as acetone, followed by casting the solution onto a revolving drum or highly polished steel belt. Once the solvent evaporates, the residue is a thin and transparent CDA film (Gear 1965). CDA films rarely consist of the pure CDA polymer, but rather contain a range of additives including small molecules that lower the melting temperature of the plastic. These additives, known as plasticizers, are typically in solid solution with the polymer (McGath 2012). The melting point of cellulose acetate without plasticizers is too high a temperature for paper (Gear 1965). Plasticizers make CDA a practical, quick melting thermoplastic material (Broadman 1945; Hofmann and Reid 1929; Turner 1957). As early as 1929, the plasticizer triphenyl phosphate (TPP) was commonly used in CDA plastics at concentrations up to 20–30% by weight (Stannett 1950). Other plasticizers have included phthalates and phosphates including dimethyl phthalate and diethyl phthalate (Ormsby 2005), and tricresyl phosphate (Stannett 1950).

Manufacturers of cellulose acetate products have included Celluloid Corporation of America, Celanese Plastics Corp., Nixon Nitration Works, E. I. du Pont de Nemours and Co. (DuPont), and Eastman Kodak Co. (Broadman 1945; Gear 1965; Law et al. 2004). Since the manufacturing process is commonly a trade secret, we do not know the exact formulation of each of the films (Gear 1965; Wilson and Forshee 1959a). The type and quantity of plasticizers (as well as other components) has varied widely, and this may have influenced the long-term stability of the laminates (Barrow 1965; Ormsby 2005; Wilson and Forshee 1959b).

The 1928 study by the National Bureau of Standards and the Library of Congress exploring the use of laminates to preserve brittle newspapers included CDA films applied with heat and pressure. Specifically, they used a heated hydraulic press to seal the document within a CDA film/document/CDA film "sandwich" (265°F, 750 psi, Figure 3(a)) (Scribner 1934). This approach minimized the thickness of the laminated document as the polymer was forced into the pores of the paper (Scribner 1934). The result of these studies was the 1934 NBS recommendation for CDA lamination for newspaper preservation, along with standards requiring stable CDA film (as opposed to celluloid film), minimal increase in the document weight and thickness, and a simple and low-cost process (Scribner 1934).

NBS conducted another round of evaluations of the CDA lamination process for use with other documents resulting in an additional publication in 1940 (Scribner 1940) and finally recommended its use at the National Archives, which had purchased its own hydraulic laminator in 1936 (Gear 1965). This was a significant recommendation considering the influx of government documents to the National Archives soon after its opening in 1934 (Scribner 1940). Thereafter the NBS continued to recommend CDA lamination as a rapid and efficient technique capable of handling massive numbers of documents. This recommendation paralleled the increasing use of CA films (of various formulations) for other archival collections in the twentieth century, including the support for many photographic films (Edge et al. 1988). It is important to note that these laminated films had

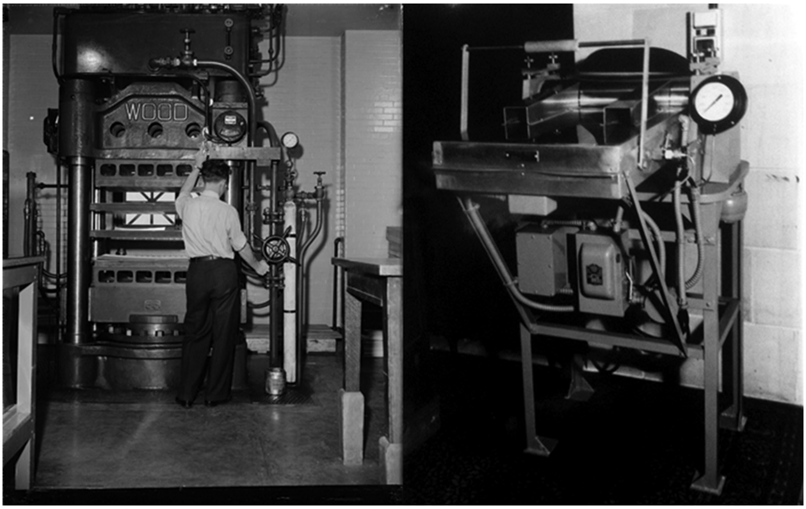

Figure 3: Left (3a): National Archives hydraulic press, photographer: Harris & Ewing, photo from Library of Congress, http://www.loc.gov/pictures/item/hec2009014402/ (accessed January 10, 2014). Right (3b): W.J. Barrow's roller press, photo from Gregory Minnick's collection, Virginia Historical Society.

imperfections that could readily be seen immediately after lamination. Observations about these films identified "bubbling" within the polymer film, delamination (Turner 1957), and slight yellowing (Scribner 1940).

Because of the cost of the hydraulic laminator, the bubbling observed in hydraulic lamination, and the stresses posed to paper documents placed at high heat and pressure for extended periods of time, William J. Barrow worked with engineers at the Mariners' Museum in Newport News, VA to invent the roller laminator, Figure 3(b) (Marwick 1964). Highlighting the advantages of his invention, he claimed it reduced the formation of bubbles in the laminate, distributed pressure more evenly over the document, and sealed edges more securely; he noted it relied on air cooling rather than artificial cooling (Barrow 1939), and reduced the time the document was exposed to heat and pressure (Turner 1957). Studies at the NBS, however, suggested that both flatbed and roller laminators were equally suitable for lamination (Wilson and Forshee 1959b). According to Barrow's company notes, his shop sold 41 roller laminators by the late 1980s (Barrow 1980–1989) and was among a number private vendors selling laminating presses including R.D. Wood and Co., the Ademco Dry Mounting Press (Kathpalia 1977), and Arbee Laminating Co. (Gear 1965). Institutions like the Maryland State Archives published the number of documents that were laminated in a year, and in a slow year this approached 9,700 pages done with a single laminator (Radoff 1944).

The roller laminator was just one of Barrow's several innovations in CA lamination. He also advocated using "a strong, well purified cellulose fibre tissue" for the outermost layer of the laminate in order to increase its tear resistance and to produce a matte finish (Barrow and Carlton 1968). While recommending Japanese tissue, other tissues were also used (Barrow and Carlton 1967). This lamination practice was supported by studies at NBS (1954–1957) showing that the addition of tissue increased the strength of the treated document (Wilson and Forshee 1959b). Barrow's protocol also called for the use of paper infills to compensate for areas of loss and maintain uniform thickness throughout the laminated document, mitigating otherwise readily perceptible effects in performance (Barrow 1970).

Barrow learned from paper scientists at the NBS the negative effects of acids in paper, and by looking at papers that had been recovered from environments containing copious quantities of calcium carbonate he began to develop methods for reducing the acid content of paper (Marwick 1964). In the late 1930s, Barrow began developing an aqueous deacidification treatment to address the issue of acidic paper (and perhaps also acidic laminate) degradation using calcium hydroxide and calcium bicarbonate baths (Barrow 1970). As an aqueous pre-treatment, his deacidification step lengthened the overall lamination process, considerably slowing what had hitherto been noted as a rapid preservation technique (Evans 1946; Nixon 1949).

Because of Barrow's several innovations, since the 1970s cellulose acetate lamination of documents – in any form – has been frequently, albeit inaccurately, referred to as "Barrow lamination", with many adopters using different supplies and following different procedures.

Indeed, over the course of the 60 years in which cellulose acetate lamination was conducted, there were numerous changes in both protocols and methods of application (Barrow 1965), as well as the formulation of thermoplastic films, including the numerous plasticizers they contained (Ormsby 2005).

A number of other conservation treatments were also investigated to treat paper. In addition to differences in laminating equipment, a range of different polymer films and adhesives were introduced throughout the twentieth century. Table 1 highlights materials and methods of other lamination processes.

1.2 Permanence and stability of CA laminated documents

CA lamination was arguably the first preservation technique to undergo extensive scientific evaluation to determine its efficacy and permanence. To understand the permanence of this technique it is necessary to understand the raw materials, the degradation of these materials both individually and when in contact with each other, and the effects the lamination method has on these materials. A first step in correctly identifying permanence issues of CA laminated documents is to identify those problems that were immediately manifest following lamination and therefore did not come about during aging. A further distinction is whether the problem is inherent to the process, or whether it is due to a failure of execution. As an example of the latter, we previously cited Barrow's observation of bubbling in the laminated film as a motivation for developing the roller press. This observation, along with delamination and separation of the film from the document directly after manufacture, are important to note because these effects can be interpreted as evidence of CDA laminate deterioration. The presence of acid also needs to be attributed to the originating source. South Carolina's Archives had to rehouse their laminated documents in the early 1970s due to acidic housing and worry of this acid transferring to the laminated documents (Lesser 2009). In response to concerns raised about the heat and pressure causing mechanical damage to the document (Ellis 1955), Werner evaluated whether Barrow lamination inherently degraded paper by measuring static tensile strength, dynamic tensile strength, and folding endurance prior to lamination and after lamination reversal, concluding that it did not "appear to have any deleterious effect upon the mechanical properties of paper" (Werner 1964). After 20 years of lamination at Maryland State Archives, the 1960 fiscal year report notes that there were no signs of deterioration (Radoff 1960).

1.2.1 Chemistry of CA laminate degradation

When assessing the aging behavior of CA laminated documents, one must consider both extrinsic factors such as environmental conditions of storage, and intrinsic factors such as material composition. There are a number of chemical mechanisms of deterioration of CA plastics that are dependent on the polymer DS and the presence of other compounds. These other compounds may be byproducts of manufacture, plasticizers, or other additives. The chemical mechanisms of deterioration include hydrolysis, oxidation, photo-degradation and plasticizer- or other additive-induced deterioration.

Hydrolysis is the most significant mechanism to CA film stability. There are two hydrolytic reactions that may occur in CA polymers: acidic cleavage of the glycosidic linkages of the cellulose backbone causing chain scission (Figure 4) or the cleavage of the ester bonds between the acetate group and the cellulose chain (Sakai et al. 1996) (Figure 2).

Sakai and coworkers showed that the acetate ester bonds are usually the first to be cleaved in the presence of either a strong acid or base (Sakai et al.

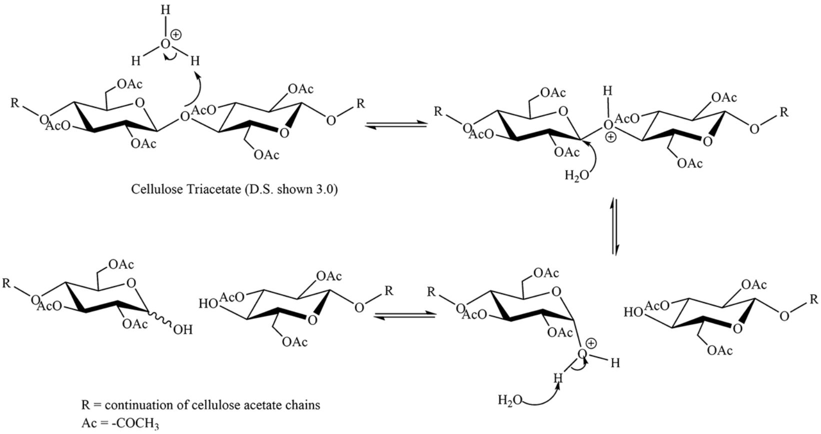

Figure 4: Acid-catalyzed hydrolytic cleavage of the glycosidic linkage of CA leading to chain scission.

1996). When an ester group is cleaved in an acidic environment it forms acetic acid. This reaction may be considered autocatalytic with the newly formed acetic acid molecules able to catalyze the cleavage of other ester groups. It is important to also note, as Knight's kinetic analysis has shown, that contrary to popular belief there is no "threshold" of acid content that will cause a devastating acceleration of autocatalysis (Knight 2014). Rather, the presence of acetic acid odour (vinegar syndrome) or mechanical failure of the film may merely indicate a certain degree of deterioration has been reached (Knight 2014). CDA is more susceptible to ester hydrolysis than CTA. This may be because CDA is more hygroscopic, having more hydroxyl groups available to hydrogen bond with water (Edge et al. 1988).

For the glycoside hydrolysis (which cleaves the cellulose backbone) Edge and coworkers demonstrated that increased temperature and moisture increases reaction rates for the photographic CDA films they tested. The reaction rate is also pH dependent, increasing from a minimum at pH 10 to a maximum at pH 4 (Edge et al. 1989b). Iron can also act as a catalyst for hydrolysis (Edge et al. 1988), making the presence of iron gall ink in laminated documents a concern.

In mechanical tests of CA fibres, both CDA and CTA lose tensile strength and elongation values when exposed to light of $\lambda = 280–235$ nm (Hon 1977). While CDA is more stable when exposed to light than is cellulose, CTA is more stable than CDA. In experiments conducted at ambient temperatures in a vacuum (to remove oxygen), photo-degradation of CTA and CDA occurred under ultraviolet light, producing carbon monoxide, carbon dioxide, and methane gases, resulting in a "loss of bound acetic acid content" with CTA producing more radical compounds than CDA (Hon 1977). This loss is more pronounced in CDA because, as suggested above, chain scission takes place more in CDA, confirmed by viscosity measurements (Hon 1977).

A major challenge in analyzing the chemistry and degradation of laminates in collections is the diversity of CDA brands and formulations during the period CA lamination was actively used. From 1936 until 1941, the National Archives used Protectoid®, a Celluloid Corp brand of film. In 1941, the National Archives switched to DuPont's 88$CA_4$8m, and then in 1957 to Celanese Corporation of America's P-911 (Gear 1965). Barrow's account books document that his shop bought CDA film from both Celluloid Corp and DuPont in 1941 (Barrow 1941). But by 1942, Barrow was only buying his CDA film from DuPont (Barrow 1942), recommending that others do the same (Barrow 1953). He continued to exclusively buy DuPont's film until it was discontinued in 1971 whereupon the Barrow Research Laboratory determined that one of Kodak's CDA films was suitable for lamination (Tushingham 1971). The latter appears to have remained in use at the Barrow Restoration Laboratory until it closed in the early 1990s. As reviewers have acknowledged, different formulations may mean different degradation mechanisms (Edge et al. 1989a; Schilling et al. 2010).

As previously noted, when a tissue was used for the outermost layer, Japanese tissue was recommended, although many types of tissues were also used (Barrow and Carlton 1967) and likely to have varied in pH and strength among the many laboratories following the basic protocol. If an acidic tissue was used, it might be expected that degradation of the CDA would be accelerated.

Finally, a central factor in the optical/physical performance of a laminated document is of course the document itself, and the conservation treatment it has undergone, if any, prior to lamination. This diversity makes side-by-side optical/physical comparisons between historical CA laminated documents difficult because, even if one knows that the materials and methods of lamination are identical, the treated paper will usually not be the same. We consider the central issue of acidic papers and deacidification prior to lamination in a section below, but other factors include localized damage due to impermanent (such as acidic) mending tissues and pastes (Barrow 1967).

While offering support, laminating a document does not necessarily slow its chemical degradation (Werner 1964). As shown above, acids may catalyze both the cleavage of the cellulose backbone in paper and the cellulose acetate backbone in a CA laminate film, weakening both materials. In addition, acids can catalyze the cleavage of ester bonds in CA, causing the release of acetic acid into the material and storage environment. Hence, the use of an acidic CA film can cause harm to the paper, and an acidic paper can cause harm to the film.

Finally, there is some concern that the CA film may create a physical barrier to otherwise volatile paper degradation products sealing them inside the laminate, an issue that is also faced with mylar encapsulation. The Library of Congress has done accelerated aging tests on mylar encapsulated documents and shown that encapsulated paper will retain deteriorating acids when closed off from the free flow of air (Preservation 2014), a finding which informs their choices as to what is encapsulated. However, even the earliest studies have shown CDA films to allow transmission of moisture vapor, albeit more slowly than cellulose (Scribner 1940), pointing towards a more permeable barrier than that seen with mylar encapsulation. Inherent advantages of the CA film laminate may include the blocking of UV light (Hon 1977; Puls et al. 2010; Giachet et al. 2014) albeit at the cost of degrading the CA film, as well as protecting the document from humidity fluctuations, polluted air, mold, pests, and microbial attack (Barrow 1943).

1.2.2 Acidity and deacidification in CA lamination

Although the role of acidity in paper degradation was known at the time of the 1928 NBS/LC newspaper lamination studies, the problem was not addressed then or in the 1934 NBS recommendations because the first deacidification method, Barrow's two-bath process, would not be developed until 1939–1940 (Barrow 1943). Thus, the NBS would only specify that the CDA film be "stable" in 1934, not that the film or paper be pH neutral. Barrow's two-bath method uses aqueous calcium hydroxide followed by aqueous calcium bicarbonate to leave a calcium carbonate precipitate within the paper (Barrow 1943). Barrow tested this deacidification in combination with lamination and recommended its use in 1943 (Barrow 1943, 1965). By 1965, Barrow had deacidified and laminated thousands of deteriorated documents in his shop and stated that he never saw any evidence that these documents became more brittle due to CDA deterioration (Barrow 1965). He said that laminated but not deacidified documents might lose as much as half of their original folding-endurance strength, while those laminated documents which had been deacidified showed a slower rate of deterioration (Barrow 1965).

By 1946, Barrow's two-bath treatment was widely known but not universally adopted (Barrow 1970; Evans 1946). The NBS did not recommend deacidification prior to lamination, nor explicitly call for pH testing of the CDA films (an expensive and difficult measurement at the time) until 1959 (Wilson and Forshee 1959b). Thus, institutions may have used acidic CDA films prior to the NBS recommendations, and may have continued to do so thereafter. Concerning deacidification, apparently some institutions that did employ the practice did not always do so for documents scheduled for lamination (Nixon 1949), and Barrow acknowledged that the efficacy of deacidification depends on the abilities of the technicians conducting the deacidification (Barrow 1943).

In 1965, when Barrow conducted destructive testing on his early laminations, two from each year between 1938 and 1965, he found CDA films purchased from 1938–1941 to be more acidic than he expected. In his notebooks, he attributed this to residual sulphuric acid from the manufacturing process. Sulphuric acid would have hydrolyzed the CDA esters and released acetic acid (Barrow 1965; Malm et al. 1946). Based on these dates, there is strong likelihood that the problem was with Protectoid® or another Celluloid Corp. film heavily used by Barrow and the National Archives in the early years of lamination. After 1941, Barrow found the films he used to be "relatively free of acid." 1941 was the year the National Archives and Barrow both switched to DuPont's 88$CA_4$8m, the National Archives continuing to use it until 1957 (Gear 1965) and Barrow until 1971. Barrow also noted that the Japanese tissues he acquired for the outer layer of the laminate over the same period were more acidic than he wished and that there was a marked improvement in pH and strength of tissue papers beginning in the 1940s (Barrow and Carlton 1967; Barrow and Carlton 1968; Barrow 1970).

1.2.3 Accelerated aging to determine permanency

The NBS recognized early on a necessity to determine scientifically the permanency of the lamination treatment. Much of the evidence presented during development regarding the relative stability of papers, films, and laminates relied on accelerated aging (Kathpalia 1960; Scribner 1934; Wilson and Forshee 1959b), including the aforementioned NBS study. The most common accelerated aging method at the time was to heat the material for 72 hours at 100°C (Evans 1946; Scribner 1940). In these tests, the relative humidity was not controlled. Folding endurance and tear resistance were the common physical tests for both paper and CDA films (Barrow 1965; Scribner 1934; 1940; Wilson and Forshee 1959b). From 1957, the NBS recommended such tests prior to the adoption of any new CDA laminating film. In the NBS study, Wilson and Forshee found that acidic papers underwent accelerated deterioration after lamination, but the lamination process did not degrade non-acidic film or paper, projecting the lifetime of deacidified laminated papers on the order of hundreds of years (Gear 1965; Wilson and Forshee 1959b). Because CA lamination behaved well in accelerated aging studies, it became increasingly accepted in the mid-twentieth century as a conservation treatment (Edge et al. 1989b).

Early criticism raised concerns regarding the ability of accelerated aging tests to accurately predict long-term natural aging of paper and laminated documents (Evans 1946). In 1946 Evans wrote that "…the permanence of lamination argument will no doubt continue until time at length supplies the answer" (Evans 1946). Evans concerns were proven at least partially correct, as a major problem with the accelerated aging conditions was the use of the hot dry oven (100°C) which did not mimic humid conditions (Porck 2000).

The stability of CA document laminates was increasingly challenged in the 1970s and 1980s (Poole 1976; Waters 1980), as discussed in Jones' 1987 article. Jones notes that the two million laminated documents at the North Carolina Archive appeared stable (Jones 1987). Stiber also questioned how universal Poole's observations of deterioration were (Stiber 1988). However, because of criticisms by Poole in 1976, many institutions began to question the use of lamination (Jones 1987). Poole wrote that "…for documents requiring archival preservation, i.e. those documents which should be expected to last at least 500 years, we now have sufficient evidence of the inadequacy of lamination to eliminate it as an acceptable technique in such cases" (Poole 1976). Poole stated that the heat and pressure inherent to the lamination process damaged documents, practitioners were not following guidelines including Barrow's deacidification recommendation, and 15–20 year old documents in the LC collection were becoming brittle within their lamination (Poole 1976). Poole credits Barrow's deacidification methods as necessary prior to lamination, but stated that some of these guidelines were not consistently carried out in restoration workshops (Poole 1976). At the time, Poole and colleagues at LC were developing polyester film encapsulation as an alternative to CA lamination for the treatment of documents (Clark 1978; Poole 1976; Waters 1980) and this technique began to largely replace CDA lamination in the following decades.

1.2.4 Issues of plasticizers in CA films

While the primary concern to early critics of CA lamination was the degradation of acidic paper, some also voiced concern that CDA plasticizers would diffuse out of the film (Broadman 1945; Clark 1978; Turner 1957), altering its flexibility and permeability. Studies were conducted to investigate how loss of plasticizer impacted flexibility, strength and delamination. It was found that when plasticizers leave the plastic, the film maintains its strength and flexibility (Gear 1957). Plasticizers aid workability during manufacture and lend flexibility to the finished product, but may separate from polymers over time, either by off-gassing or exuding as a liquid or solid. Volatile plasticizers such as dimethyl phthalate and diethyl phthalate were commonly incorporated into CA films, paired with nonvolatile triphenyl phosphate (TPP) to reduce their evaporation rate, at total plasticizer concentrations up to 20–30% by weight (Stannett 1950; Sully 1962). As early as 1929, TPP was viewed negatively within the plastics industry. It crystallized within plastic films as they aged which impaired their flexibility (Hofmann and Reid 1929). However, in degradation tests on laminating films, TPP was found to act as a stabilizer and thus was recommended as a plasticizer for laminating films (Wilson and Forshee 1959b).

By 1988, CA films 40–50 years old were beginning to deteriorate, prompting Edge and coworkers to study plasticizers in cinematographic CA film (Edge et al. 1989a). They observed crystalline deposits on the film surface and an acetic acid odour. In significantly deteriorated regions of the film, they measured a disproportionate concentration of TPP using infrared spectroscopy (IR). It should be noted that these studies focus on photographic films, which have shown different stability than laminated documents, as evident by the common use of cold storage for acetate photographic film, while cold storage for laminated documents has not been documented. Dimethyl phthalate and diethyl phthalate are also known to have caused long-term stability problems for CA plastics, as these are volatile plasticizers even within intact cellulose acetate that cause shrinkage and warping of the plastic as they off-gas (Sully 1962).

Investigation into the chemical stability of a collection of CDA laminated materials was conducted by Grundy and Kennedy at the National Anthropological Archives. The NAA's collection of documents was laminated by the preservation division of the National Archives from the 1950s–1970s (Grundy and Kennedy 2002). These documents were not deacidified prior to lamination. Evaluating five samples from each decade, Grundy and Kennedy assessed the structure and deterioration of the laminated documents using scanning electron microscopy–energy-dispersive x-ray spectroscopy (SEM-EDX), solid phase micro-extraction (SPME), IR, pH measurements, and free acetic acid tests using A-D test strips. Their SEM-EDX results showed evidence of paper splitting at the penetration line of CDA with a paper pH of about 5.5. This suggests that lamination may be damaging the document even before deterioration is visibly detected. The SPME and IR results on a series of 59 artifacts revealed diphenyl phthalate and diphenyl cresyl phosphate as potential plasticizers in the plastic, but over half of the objects did not appear to have plasticizers present. The plasticizer identification was preliminary. Interestingly, acetic acid tests did not show any off-gassing of acetic acid over the 96 hour study, though the amount given off may have been below the test level of the A-D test strips (Grundy and Kennedy 2002).

1.3 Removal of CA lamination

From its early years, CDA lamination had been promoted as a reversible treatment by its proponents (Wilson and Forshee 1959b). In the last two decades, conservators have sporadically removed CDA lamination of documents, reportedly either to fix visible problems or mistakes in execution, or to prevent future physical or chemical damage to the documents induced by the CDA degradation mechanisms (Grundy and Kennedy 2002). This reversal – commonly called delamination – generally uses a sequence of acetone baths (personal communications with conservators 2014). The solubility of CA in various solvents is dependent on the acetyl content (degree of substitution, DS). As shown in Table 2, CDA (DS 2.3-2.7) is soluble in acetone. A CDA film laminated onto paper swells in an acetone bath, weakening the CDA/paper interface, allowing the CDA film to be peeled away. This treatment is of course only available with compatible media, thus excluding aniline dyes, wax crayons, copy pencil, etc. which are soluble in acetone (Grundy and Kennedy 2002).

Table 2: Solubility of cellulose acetates based on acetyl content.

DS (Acetyl content %)	Solubility
2.8–3.0[a]	Chloroform soluble
(43.0–44.8%)[b]	Dichloromethane soluble/Acetone insoluble
2.2–2.7[a] (37–42%)[b]	Dichloromethane insoluble/Acetone soluble
1.2–1.8[a] (24–32%)[b]	Acetone insoluble/2-methoxyethanol soluble
0.6–1.0[a] (15–20%)[b]	2-methoxyethanol insoluble/Water soluble
$\leq$ 0.4[a] ($\leq$ 13%)[b]	Insoluble in all solvents listed

[a]Balser et al. (2003), [b]Gedon and Fengi (2004).

There are variations in the reported method and difficulty of delamination treatment, with some conservators indicating it is easy and straightforward, and others saying it is difficult and time-consuming, requiring harsher organic solvents (personal communications with conservators, Page 2003). One explanation for this variability is perhaps to be found in the CDA ester hydrolysis degradation mechanism given above. While CDA is soluble in acetone, unsubstituted cellulose is not. As a CDA laminate film loses acetyl groups due to hydrolysis, it becomes progressively less soluble in acetone (Balser et al. 2003; Gedon and Fengi 2004), and more difficult to separate from the paper. The implication would be that when a CA laminated document is at risk of ester hydrolysis because it is acidic or exposed to high humidity, there may be a limited time in which reversal of the lamination is feasible, and there may not be visible clues that this hydrolysis has occurred.

1.4 Motivations for further study on CA lamination

Many questions remain about CA laminated document collections in the United States. We do not know, for example, how many CA laminated documents may exist in US collections. Although we know CA lamination protocols, such as those of the National Archives and Barrow's laboratory, we do not know their distribution within and among collections. Several authors suggest (Barrow 1943; Gear 1965; Kathpalia and Gear 1958; Scribner 1934; 1940) that there were differing motivations for carrying out lamination, but we do not know how documents were selected for lamination and if there was a preference for laminating particular document types. While we have observed laminated documents in excellent and poor condition, we do not know how conservators and collection managers describe the present condition of CA laminated collections. Finally, while the prevention of damage to the document has been cited as a reason for removing lamination (Grundy and Kennedy 2002), we do not have a full understanding of the reasons motivating institutions to delaminate, or the number of laminations that have been removed in CA laminated collections in the US. These questions motivated the survey of US collections reported below. We hope that the results of this survey will be useful to institutions when comparing their CA laminated collections with others, aiding in preservation strategies such as assessing the cost versus the benefit of delamination, and identifying avenues of future research.

2 A survey of CA laminated documents in the United States

2.1 Survey method

We deployed an online survey of libraries, archives, and museums professionals at 89 US institutions selected based on Marwick's prior (Marwick 1964) survey list, Barrow's list of laminator purchasers (Barrow 1980–1985), institutions identified in the literature as having performed lamination (Barrow 1939; Gear 1965; Jones 1987; Poole 1976; Radoff 1941) and institutions identified as having significant paper-based collections. The institutions included federal, state, county, local, and private libraries; archives; and museums. They ranged from large to small and included at least one from every US state.

Respondents were asked to answer the questions to the best of their ability, skipping those they could not answer and providing more than one answer where necessary. Up to 39 questions were asked to each respondent depending on initial answers to core questions of whether the institution conducted lamination, currently holds laminated documents, has observed deterioration in these artifacts, has removed lamination, and whether the storage environment has been environmentally controlled.

The survey was open June 27–August 31, 2014 (65 days) and received 52 complete responses. It was distributed and collected via the online SurveyMonkey® platform and was self-administered, meaning that respondents read and completed it without assistance. The data were then made anonymous and normalized to the number of total responses. All percentages given hereafter are of the responding institutions. Additional details about the survey administration are available upon request.

2.2 Survey results and discussion

Based on the 52 responses, 74.5% of institutions report having laminated materials in their collections. Of these, 65% specified that their collection contained CDA laminates. Therefore, 24 institutions out of the 52 respondents had CDA laminates in their collections, 4 did not, and 9 were unsure. Two institutions report having more than 1 million CA laminated documents in their collections, approximately 75% have fewer than 100,000, and three institutions were unsure of the number. Adding the minimum values from each of the responses, we estimate from the survey alone that there are at least 2.9 million laminated documents housed in U.S. collections today.

The literature provides evidence of much higher numbers. Jones' article provides a 2 million documents estimate for the North Carolina State Archives (Jones 1987). The Library of Congress's annual reports list 90,000 documents and 20,000 maps in a single year of lamination (Mumford 1966), and employed at least two laminating machines. Delaware laminated 5,000 manuscripts in their first year of lamination (deValinger 1965), given this as a minimum, the total for the 25 years from their first use to deValinger's publication is 125,000 manuscripts. The Maryland State Archives fiscal year reports 11,000 pages in a slow year with one press and one to two users (Radoff 1945). With 50 years of use, a low estimate for Maryland State Archives is 500,000 pages. The South Carolina State Archive was averaging 65,000 documents a year in the 1970s

(Lesser 2009), giving a total of 650,000 documents for the 1970s. Pennsylvania State Archives have documented 144,000 laminated land surveys alone (Ries 1997). Using only these estimates and documented numbers, the total number of laminated documents exceeds 3.5 million. This number represents only a handful of institutions and years of lamination. It does not include large institutional users like the National Archives, for which ready numbers were difficult to find. The National Archives, which began laminating in the 1930s, had three lamination machines by 1965 (Gear 1965), so the number of laminated documents from that institution alone would be huge. This is all to say that the survey estimate of 2.9 million laminated documents is on the very low end. Perhaps this low estimation is tied to the fact that lamination was ceased in most institutions over two decades ago. This fact should be considered while evaluating all of the survey data.

The distribution of document types that are laminated in respondents' institutions is given in Table 3. More than 75% have manuscripts, 75% have letters, and 60% have maps. Other formats included government documents, photographs, drawings, and other archival records. The range of media in laminated documents is given in Figure 5, with Iron Gall Ink especially prominent at over 60% of institutions with CDA laminated documents.

Table 3: Question – What kinds of documents were laminated? Please check all that apply.*

Type of document	Number of institutions checking this box	Percentage of institutions who answered this question
Manuscripts	25	78.1
Letters	24	75.0
Maps	19	59.4
Newspapers	15	46.9
Books	11	34.4
Others (please specify)	9	28.1
Government Documents	5	15.6
Photographs	1	3.1
Drawings	1	3.1
Other Archival Records	1	3.1

*Note: 32 participants (61.5%) answered this question.

Respondents gave different reasons for laminating documents (or having them laminated) with single institutions commonly reporting more than one reason, often including that they were unsure of all of the reasons for laminating. Figure 6 shows the distribution of reasons for laminating. The most common

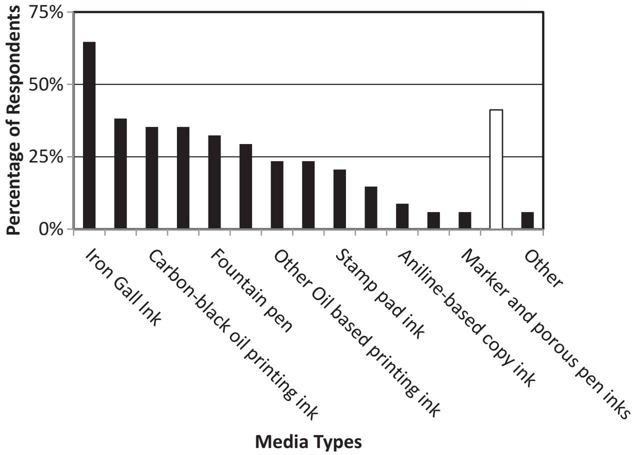

Figure 5: Types of media laminated.

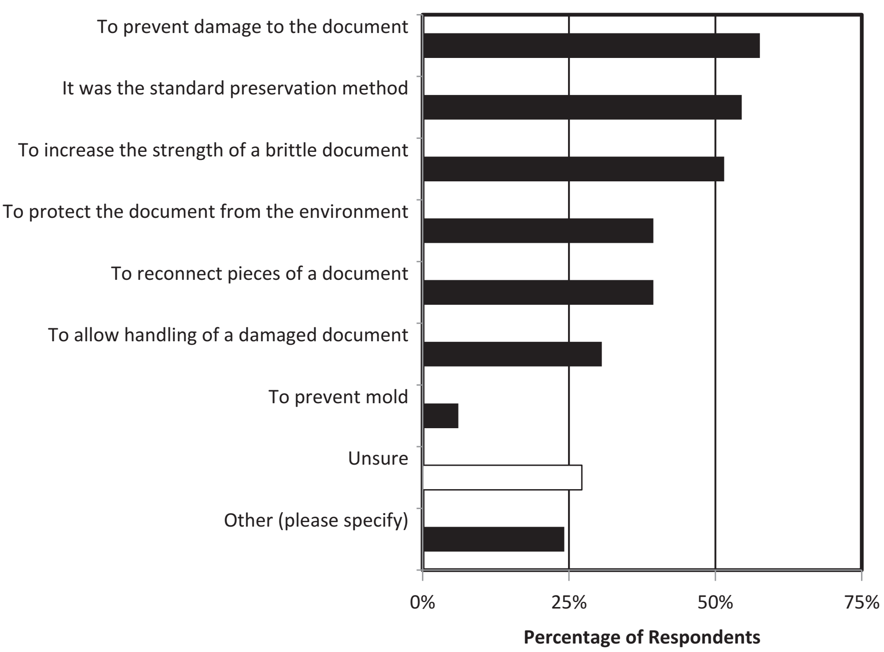

Figure 6: Reasons for lamination at respondent institutions.

reasons were to prevent damage to the document, because it was the standard preservation method, and to increase the strength of a brittle document. Almost ¼ of respondents supplied additional information. Two of these stated that it was done to improve accessibility, and two stated that they inherited these materials and do not know the reason for their lamination.

At the majority of institutions (58.6%) document lamination was conducted in-house exclusively; 20.7% outsourced the treatment, and another 20.7% did both. Of those who outsourced the treatment, most could not name the vendor. However, amongst those who could name the vendor, William J. Barrow's Restoration shop was the most common vendor reported, but Gregory Minnick, Gale Fields, and Ham Rebinding were also reported by one institution each.

Participants were asked to identify the decades during which lamination began, and ended, at their institutions. As shown in Figure 7, the white bar indicates when lamination began and the black bar when it ended for each decade. Almost half of the institutions (46.7%) reported that lamination started prior to 1960. The bulk of lamination ceased during the 1970s and 1980s.

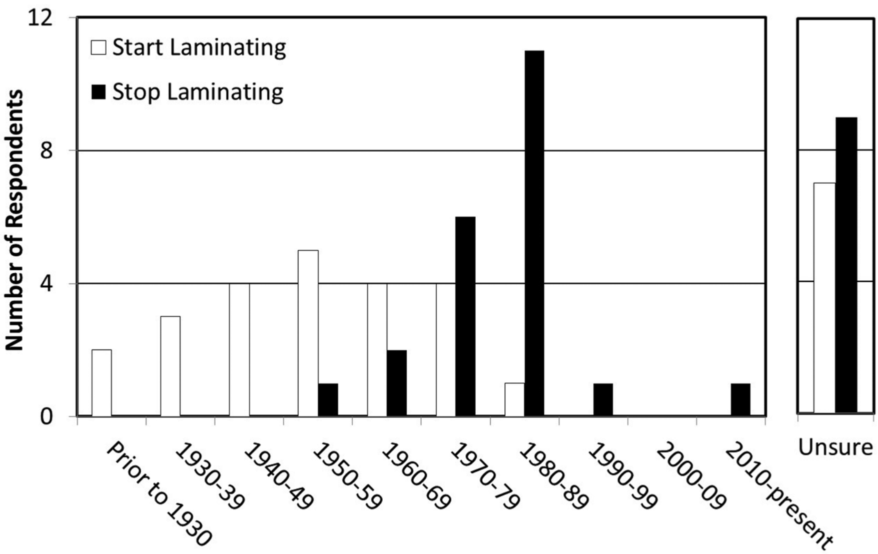

Figure 7: Number of respondents who started laminating (white) and stopped laminating (black) in a given decade.

Asked if they could identify the type of lamination employed at their institution, 29.4% responded that they would definitely be able, 41.2% that they might be able, and 29.4% that they definitely would not be able to identify the method of lamination. The most common method identified was CDA lamination with heat and pressure, either with tissue (58.3%) or without (25%). Other responses included Morane/Ultraphan Process (cellulose acetate film bonded using a heat-sensitive adhesive, 8.3%), Mylar-polyethylene composites (4.2%), Postlip Duplex laminated tissue (4.2%), Polythene (4.2%), and soluble nylon (4.2%). Three other options given on the survey, the Goel Process (Goel 1953), Mipofolie process, and Sundexing (Darlington 1955), were not chosen by any of the respondents.

The survey used a Likert scale assessment to ask respondents about the condition of their laminated documents. The respondents were asked to self-identify as being able to comment on the condition of the laminates. Of the respondents, 76% agreed that they could comment on the condition of the laminates and 20% were unsure. Respondents were then asked to use a Likert scale of “mostly good”, “somewhat good”, “highly variable”, “somewhat bad” and “mostly bad” to identify the condition of their laminated documents without further description. Thus for assessment of what constitutes “mostly good” or “mostly bad” the survey depends on the experience of the respondents. Of those able to comment, 57.1% replied that the majority of their laminated documents were “mostly good,” 19% “somewhat good,” and 19% “highly variable.” Only one institution reported “somewhat bad,” and none reported “mostly bad.” The assessment that 76% of a class of documents requiring intervention from the 1930s–1980s are today deemed in either “mostly good” or “somewhat good” condition presents an overall positive picture of cellulose acetate lamination as a conservation treatment. Whether the observed condition, however, masks degradation present (though not yet visible) is unknown. It is also possible that there may be a bias in these assessments in that the removal of the poorest laminates may have prompted an overly positive view of the treatment.

While most laminated collections are in reportedly stable condition, respondents observed several types of laminate and paper degradation. The question asking respondents to characterize laminate deterioration was the most commonly (67.3%) omitted question of the survey. Of those 17 institutions that answered, the most prevalent forms of deterioration were cracking (58.8%) and darkening (of the paper) (58.8%), followed by bubbling (of the film) (47.1%), delamination of the film and/or tissue (47.1%), breaking (of the artifact) (35.3%), media discoloration (35.3%), paper curling/changing shape (35.3%), and vinegar odour (29.4%). Figure 8 illustrates some of these failures.

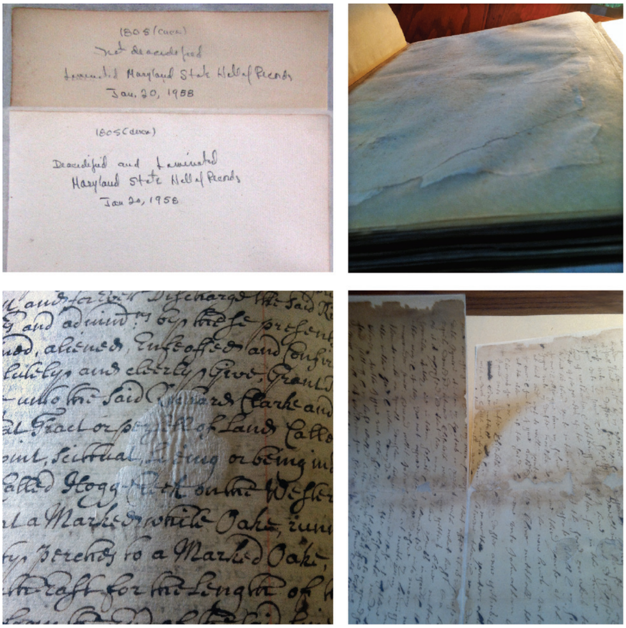

Figure 8: Examples of deterioration observed in laminates. Top left: Darkening of the paper laminated without prior deacidification (top sheet) compared sheet deacidified prior to lamination (bottom sheet) (Barrow Lamination Collection JHU, laminated in 1958 at Maryland State Archives) Top right: physical distortion, (MSA C681-3: Charles County Wills Liber J, laminated in 1941) Bottom left: bubbling of the laminate (MSA C710-5: Dorchester County Land Records, No. 5, 1692–1701, laminated in 1946) Bottom right: cracking of the laminate (MSA C1327-2: Prince George's County Original Wills Box 2, 1713–1721, laminated in 1948), Photos courtesy of Maryland State Archives.

If CDA degradation were the major cause of overall CDA lamination deterioration, the oldest laminates would be the most deteriorated. When asked whether there was an obvious correlation between the date of lamination and the current condition of laminated documents, 50% answered “unsure”, 25% answered that there was an obvious trend, 25% answered that there was not an obvious trend.

In the nearest response to unanimity in the survey, all but one institution reported that the laminated documents were entirely stored within environmentally maintained storage. Because environmentally maintained storage will reduce degradation of CA laminated documents, specifically hydrolytic degradation, this suggests that the variation in condition reported is not due to environmental factors.

We included a series of questions to better understand deacidification as a pretreatment for document lamination within institutions. First, respondents were asked whether any documents were deacidified at their institutions. Of the 41 respondents, 58.5% indicated that some of their materials had been deacidified, 22% were unsure, and 19.5% indicated that none were deacidified. Approximately 68% reported that their institution performed the deacidification treatment in-house, 16% that their institution did not, and 12% that their institution sometimes deacidified. A majority of the respondents (68%) could identify the type of deacidification treatment performed, 20% were unsure, and 12% could not identify the type of treatment. The respondents were next asked about the relationship between deacidification and lamination (29.2% stated this was not applicable to their collections). To the question of whether deacidification was conducted prior to lamination, many of the respondents (47.6%) reported that their institution did deacidify prior to lamination, 23.5% did not, 17.6% did not always deacidify, and 11.8% were unsure. For the type of deacidification conducted, most of the respondents (56.3%) reported that they used Barrow's two bath method, 43.8% used the Wei T'o system, 18.8% used magnesium bicarbonate, and 12.5% used calcium bicarbonate/calcium carbonate. The following methods were used by one respondent each: Calcium hydroxide, calcium-magnesium bicarbonate, and CSC Booksaver®.

Bringing together the results for the last three criteria – age versus condition, climate control, and prior deacidification – the variable condition of laminated documents is apparently not due to a lack of climate control or the inherent degradation of CDA films. Rather, differences in the treatment materials and methods, including the application of prior deacidification and the variation in commercially produced laminate films are the most likely explanations for observed deterioration of CA laminated documents in US collections today. Part of the explanation for about 40% of responding institutions not deacidifying may be the time involved in testing a collection for pH and deacidifying prior to what was otherwise a rapid process of lamination.

Asked whether lamination removal has been attempted at their institutions, 45.2% of respondents had not delaminated any documents, another 41.9% had performed some delamination, and 12.9% were unsure. Of the 13 respondents who had delaminated materials, 61.5% performed delamination in-house, 23.1% outsourced the treatment, and 15.4% did both. Of the respondents that delaminated, 61.5% reported having delaminated fewer than 100 documents, 15.4% delaminated between 101–1,000, and 15.4% delaminated between 1,001 and 5,000. Only one institution had delaminated between 5,000–10,000 documents. Calculating the sum of delaminations performed by responding institutions, using the maximum value for each range (16,100) – and the minimum sum of laminated documents in respondents' collections (2.9 million) – we estimate that at most 0.6% of laminated collections surveyed have been delaminated.

Delamination methods using organic solvents were the most reported (76.9%). Of these, 46.1% used an acetone bath but 30.8% did not indicate the type of organic solvents used. 38.5% reported a treatment using at least some water and 15.4% reported that the bath contained water exclusively, 15.4% reported using mechanical methods of delamination and 15.4% were unsure how the lamination was removed. The respondents that report using only water did not outline how they were able to do delamination with water alone, so we can only postulate. It may be that while the CDA film is not soluble in water, partial delamination could be accelerated using water to swell paper and pop the film off of the document, a much more mechanical method of removal. To the question of why delamination was done, responses vary widely: 63.6% said it was in response to evidence of degradation, 54.5% that it was in response to spontaneous delamination, 45.5% that it was a tactile perception of damage to the item, 36.4% that a vinegar odour was present, 27.3% because they heard that lamination was bad for the document, and 9.1% that it was a visual perception of damage. Other stated reasons for delamination included: preparation for an exhibition, significance of the document, poorly executed lamination, misaligned fragments in the lamination, and they were only testing how to delaminate. Asked how difficult delamination was to perform, 54.5% said that the difficulty varied with each artifact. As suggested in the introduction, this variability may be due to the decreasing solubility of CDA in organic solvents as it ages. Indications that this treatment can prove difficult, that it is a large investment in staff time and equipment, and the fact that only one institution has performed it on 5,000–10,000 documents, substantiate the estimate that very few, about 0.6%, of laminated documents in US collections have been delaminated.

3 Conclusions and future work

Cellulose acetate lamination was a widespread preservation technique used in the twentieth century primarily to preserve brittle paper. Since its inception, concerns about the lamination method have been raised regarding the physical and chemical instability of the laminate and the degradation risks posed to the treated document. Today, many cellulose acetate laminated objects exist in US collections. In some cases, the cellulose acetate film and/or underlying document has degraded whereas in other cases the cellulose acetate film is in excellent condition. The reasons for this disparity likely include different lamination methods and raw materials and variations in pre-treatment of the original document. Removal of the cellulose acetate film is costly and time intensive and will impact the budget and management of laminated collections at institutions.

A survey of 52 US institutions with significant laminated collections was conducted in an effort to understand the breadth and condition of cellulose acetate laminated documents in US collections. The results of the survey are:

- At least 2.9 million laminated documents exist in US collections today. A majority of the institutions surveyed used cellulose diacetate (CDA) as the laminating film.
- Lamination was reportedly carried out to serve differing preservation objectives. These include to restore strength, to prevent degradation, and simply because it was a standard protocol.
- Most cellulose acetate laminated documents are reportedly in stable condition. Specifically, 57% are in “mostly good” condition and 19% are in “somewhat good” condition.
- Several distinct types of laminate and paper degradation can be observed. Problems reported, from most common to least common, are cracking and darkening of the paper, bubbling, delamination and breaking of the laminate film, media discoloration, and vinegar odour.
- The observed condition of laminated documents does not directly correlate with age. Differences in the treatment materials and methods, including the application of prior deacidification and the variation in commercially produced laminate films, are a likely explanation.
- In US collections, as few as 0.6% CDA laminated documents have been delaminated.

Further work is needed to correlate important lamination variables to the present observed condition. For example, how does the presence of certain plasticizers, in what distribution and in what form, relate to the present condition of the document or laminate? What is the relative contribution of paper acidity versus the degradation of the CA film (mainly glycoside hydrolysis and ester hydrolysis) in the degradation of the document or laminate? How does the degradation of CDA affect the ease of laminate removal? Using chemical and physical analysis, we aim to address these issues. The results should be particularly useful in the treatment and management of cellulose acetate laminated collections.

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Zusammenfassung

Celluloseacetat-Laminierung: Literaturübersicht und Umfrage in Archiven und Sammlungen in den USA

Bei der Celluloseacetat(CA)-Laminierung wurden Dokumente zwischen thermoplastischen Folien versiegelt, um sie dadurch zu verstärken. Die Technik war von den 1930er bis zu den 1990er Jahren weit verbreitet. Allerdings führten Zweifel an der physikalischen und chemischen Stabilität des Laminats und Untersuchungen zu Risiken für die behandelten Dokumente in den 1980er Jahren zu einer schrittweisen Einstellung der Laminierung. Trotz Bedenken an der CA-Laminierung wurde bislang kein koordinierter Versuch zur systematischen Beschreibung der verschiedenen Materialien und Techniken, die dabei zum Einsatz kamen, unternommen. Auch gibt es keine Schätzungen, in welchem Umfang Dokumente in Sammlungen in den USA laminiert wurden und in welchem Zustand sich diese befinden. In dem vorliegenden Beitrag werden Materialien und Methoden der CA-Laminierung beschrieben und die Ergebnisse einer Befragung von 52 Institutionen in den USA, in deren Sammlungen sich eine große Anzahl an laminierten Dokumenten befinden, zusammengefasst. Laut unserer Studie existieren ca. 2,9 Mio. laminierte Dokumente in Sammlungen in den USA, wobei sich die meisten dieser Dokumente in einem stabilen Zustand befinden. Ein Großteil der Institutionen verwendete Cellulosediacetat (CDA) als Laminierfolie, und nur 0,6% CDA-laminierte Dokumente wurden bis zum gegenwärtigen Zeitpunkt delaminiert. Die Ergebnisse der Studie können Institutionen im Umgang mit laminierten Sammlungsbeständen und bei damit verbundenen Kosten-Nutzen Rechnungen unterstützen.

Résumé

Laminage à base d’acétate de cellulose: examen de la littérature et vue d’ensemble des collections à base de documents papier aux États-Unis

Le laminage à base d‘acétate de cellulose, une technique de renforcement des documents par scellement entre des feuilles de film thermoplastique, a été généralisée entre 1930 et 1990. Son utilisation a progressivement cessé dans les années 1980 à cause des préoccupations au sujet de l‘instabilité physique et chimique du stratifié et des risques de dégradation du document traité. Malgré les inquiétudes concernant le laminage à base de cellulose d‘acétate, aucun effort coordonné n’a eu lieu pour établir une vue d’ensemble des différents matériaux et techniques utilisés pour le laminage à base de cellulose d‘acétate ni pour déterminer le nombre et l‘état actuel des documents stratifiées à l’acétate de Cellulose dans des collections américaines. Dans cet article, nous examinons la chimie et les méthodes utilisées pour le laminage à base de cellulose d‘acétate. Nous rendons compte ensuite des résultats d‘un sondage dans cinquante-deux institutions des États-Unis possédant d’importantes collections de documents laminés. Nous constatons qu’au moins 2,9 millions de documents laminés existent dans les collections américaines et que la plupart de ces documents sont dans un état stable. La majorité des institutions ont utilisé du diacétate de cellulose comme film de laminage et que seulement 0,6% des documents laminés avec du diacétate de cellulose ont été délaminés. Les résultats de cette étude devraient aider les établissements dans leur analyse coût/bénéfices pour la gestion de ces importantes collections.

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