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The Use of Different Techniques for Removal of Pressure-Sensitive Tapes from Historical Paper Documents: A Review

Wafika Noshy Wahba [a], Nermin Moustafa Shoshah [b], Hanaa E. Nasr [c], Gomaa Abdel-Maksoud [a*]

[a] *Conservation Department, Faculty of Archaeology, Cairo University, P. O. 12613, Giza, Egypt*
[b] *Conservator, Graduated from the Conservation Department, Faculty of Archaeology, Cairo University, Giza, Egypt*
[c] *Polymers and Pigments Department, Chemical Industries Institute, National Research Centre, Dokki, Giza, Egypt*

Abstract

Manuscripts and historical documents are present in large numbers in museums, libraries, and archives. They represent an invaluable value. However improper restoration represents a significant problem for manuscripts and documents and sometimes leads to their loss. One of the most important improper restorations is the use of pressure-sensitive tapes. This study aims to present integrated research on the problem of using these tapes in all their dimensions and to provide solutions used globally in this field. The history of using the pressure-sensitive tapes, their structure, the effect of aging on different types of tapes, deterioration forms, and their deterioration mechanisms were well explained. Different techniques (The traditional and advanced techniques) used for the removal of these tapes were described. The results showed that both traditional and advanced methods removed the pressure-sensitive tapes and improved the surface of the deteriorated manuscripts. On the other hand, it can also be said that there are some disadvantages that can be obtained from the traditional methods, and many advantages that can be obtained from advanced techniques. The study also confirmed that the choice of the technique used to remove pressure-sensitive tapes depends mainly on the state of the manuscript or the document itself.
Keywords: Historical documents, improper restoration, pressure-sensitive tapes, aging, traditional cleaning, gels, laser cleaning.

1. Introduction

Historical paper manuscripts are found in large quantities in museums, storage, libraries, archives, etc. They contain different values (historical, religious, aesthetic, etc.). Documents especially paper manuscripts are exposed to damage due to unsuitable surrounding environmental conditions such as fluctuation in temperature, relative humidity, and light, in addition to the main problems of air pollution for manuscripts, especially in the case of high relative humidity. Biological damage by insects and microorganisms, including the acids or enzymes they secrete, plays a significant role in damaging manuscripts. In addition to all of the above mentioned human damage of improper use and handling, and lack of complete and in-depth scientific knowledge of restoration methods can also add to many aspects of the deterioration of manuscripts [1]. Paper manuscripts and documents should be preserved and conserved from the environmental conditions [2-13].

With the great scientific progress in conservation field, especially restoration and conservation of manuscripts, some ancient treatment methods that were good at the time of their application were evaluated, and it was found that some treatment methods led to an increase in the deterioration of manuscripts with the help of unsuitable environmental conditions as was mentioned above.

One of the most important problems caused by the previous restorations is the use of pressure-sensitive tape, which has been used to reassemble pieces of paper together, repair tears, etc. This method was common in the restoration of historical paper manuscripts. Its use has been encouraged because its application is easy and inexpensiveness. It should be mentioned that it did not give any defects during its application. With natural aging time when surrounding

*Corresponding author e-mail: gomaa2014@cu.edu.eg (Gomaa Abdel-Maksoud).
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environmental conditions were unsuitable, some disadvantages appeared on the historical paper as a result of its application. Some of these disadvantages are discoloration, yellowing, brown spots, paper transparency, the stickiness of the adhesive, oiliness, hardening and, paper splitting, wavy, fragility, and shedding of tears. The bleeding of inks and increasing the acidity of the paper were also noticed [14].

The authors have attempted to solve the pressure-sensitive tape problem during the last two decades of the twentieth century and into the twenty-first century. They have used many traditional and advanced methods to remove it. Some traditional methods such as heat, eraser, and solvents have been used [15-16].

The methods of removing the pressure-sensitive tape have been developed. Lasers were used [17]. Rigid Polysaccharide Gels such as Agarose and gellan gum were also used [18]. Vallieres [19] has used solvent gel such as gellan solvent gel, and Tengelin [20] has also used agar solvent gel. Highly retentive hydrogels loaded with eco-friendly environmental nanostructured fluid have been used [21, 22]. Organogels loaded with diethyl carbonate have also been used [23, 24].

Analysis and investigation are vital in the conservation field [25-33], especially when dealing with an improper old restoration such as the use of pressure-sensitive tapes [34]. Analysis and investigation reveal the degree of deterioration, explain the deterioration mechanisms [35, 36], and they are useful for the evaluation of the materials and methods used in the conservation.

This study aims to produce an integrated study, which presents the problem of the using pressure-sensitive tapes in the restoration of old documents; the forms of deterioration, explain the deterioration mechanism; and produce the solutions for solving this problem using traditional and advanced treatment techniques for removal of the pressure-sensitive tapes.

2. History of using pressure-sensitive tape

Bonelli [21] reported that pressure-sensitive tape was first used in 1845 by Dr. Horace Day, a surgeon, who devised the first surgical sticking plaster tape using a mixture of India rubber, pine gum (the tackifying resin), turpentine (the solvent dispersant), litharge (the filler), and turpentine extract of cayenne pepper. He applied the mixture to strips of fabric. Smith [15] and Trabace [23] reported that the next major application for pressure-sensitive tape came from the automotive paint industry in 1920, because they found some defects in surgical tape in this field. Accordingly, Minnesota Mining and Manufacturing Company (3M) developed a new pressure-sensitive tape with paper backing coated with a rubber adhesive, various oils, and resins to fit the requirements of the automotive paint industry. The name of this tape is masking tape, which was invented by Richard Gurley Drew in 1925. The natural rubber adhesive component was gradually replaced with synthetic-based mixtures, and a new transparent backing called cellophane tape, which was the first "Scotch Brand product in 1931 [36]. Smith [15] said that in the 1950s cellulose acetate was used as tape backings. Synthetic polymers mixed with resins were used as adhesives. , Among the first of these tapes was Scotch Brand #810 Magic Mending Tape. In less than sixty years, 3M Campany alone manufactured 1000 different tapes.

After this huge development, the 1970s saw pressure-sensitive tapes marketed as "archival" like Filmoplast P and Filmoplast P90., These types of tapes have thin paper backings which contain alkaline salts Synthetic polymeric adhesives are often combined with vinyl acetate or were plasticized with phthalates. Although acrylic tapes appeared, they did not replace cellophane rubber tapes because acrylic adhesives are very expensive [36].

Regarding the use of pressure-sensitive tape in preparing documents, the first indication was in 1956 when Ray mentioned the use of Scotch tape to mend torn pages of temporary value. It should never be used to repair or preserve of papers of permanent value, although it does not turn yellow or become brittle with age [37]. Tengelin [20] reported that natural resins, waxes, and fillers were mixed with natural rubbers to produce a heterogeneous product with specific properties, but it was not good. In the 1970s - the development of Document Repair Tape at the British Library.

3. The structure of pressure-sensitive tape layers

According to Smith [15], the pressure-sensitive tape consists of four component layers (Fig. 1):

- The first layer (The adhesive mass): it is usually composed of a natural or synthetic rubber which was used instead of natural rubber during its lack during the World War II such as Polyisoprene and styrene-butadiene [38] or acrylic polymer, which forms the basis of a pressure-sensitive adhesive, and it may contain a variety of plasticizers as mineral oil, lanolin, the phthalate, and phosphate plasticizers which make elastomer a softer and is compatible with the surfaces on which the pressure-sensitive adhesive is applied. The Fillers are also added to increase adhesive viscosity and reduce the cost. The color also was added like titanium dioxide. Finally, the antioxidants are added to stabilize pressure-sensitive adhesives against heat and light degradation, as well as against oxidation, etc. [15, 36].
- The second layer (The backing or carrier): This layer may be made from foil, paper-like crepe paper, fabric like Woven fabric, film-like cellophane, cellulose acetate, plasticized polyvinyl chloride, and polyester, or any of a number of other flexible materials, which may be reinforced

with glass or polyester, or nylon filament, or polyester, or nylon filament [15, 16].

- The third layer (The primer coat): This layer is less transparent but equally important layer located between the adhesive and the backing layer to ensure good adhesion between them. . It consists of natural or synthetic elastomers and may contain some tackifiers like resins or rosins, which are brittle solids that impart the property of "quick-stick" to the rubber materials. They can form 50-75% of rubber-based mixtures [36].
- The fourth layer (the release coat): It is applied to the side of the backing that is away from the adhesive mass, so the roll can be unwound without leaving any residual adhesive.

4. The effect of aging on different types of pressure-sensitive tapes

4.1. The effect of aging on the components of the natural rubber-based tape

Experimental studies made by Feller [35] proved that light tends to cause little changes of rubber but not to speed up the basic rate at which the predominant deterioration reactions in polymers and resins occur. Tackifiers such as resins and rosins contribute to the instability of rubber-based adhesives, for example, Wood rosin is susceptible to oxidation due to the presence of conjugated double bonds in its structure, discoloration to brown and Form a small crystal in the adhesive that can be recognized by critical eye [36]. As a result the Chemically-modified rosins are exposed to oxidation during manufacture because the resin molecule usually contains more activated positions resulting in the formation of peroxy radicals which often react with the rubber elastomer. The adhesive becomes very sticky, and the rubber molecules become small enough to migrate into a paper. Fillers, such as titanium dioxide, can activate the oxidative decomposition of the adhesive components. Although the antioxidants added to the adhesive protect it from aging, with oxidation they are a source of staining of the adhesive. (For example, phenols are not highly destructive, but when oxidized, they form a highly colored quinoid). Fluctuations of temperature promoted the migration of plasticizers such as mineral oil and lanolin through the paper because a plasticizer's solubility parameter is dependent on temperature, which leads to the transparency of paper.

4.2. The effect of aging on the components of tape-based on Synthetic adhesives polymer

Polyacrylate is a naturally viscous material that is sensitive to pressure without additives. . Due to The polymer being saturated and more resistant to oxidation and aging than rubber-based adhesives, they are unlikely to change the color to dark brown or become hard [16]. However, manufacturers add tackifier like rosin esters and polystyrenes to change or modify the adhesive properties. As with rubber-based adhesives, the tackifier can promote the chemical instability of the adhesive. The plasticizer such as butyl benzyl phthalate is also added to the acrylic adhesives. but the adhesives are vulnerable to the loss of plasticizer through migration and volatilization. Acrylic tapes have been observed to cause bleeding of some inks and paper transparency (It is a case that is associated with the plasticizer in the adhesive) [36]. Acrylic-based pressure-sensitive adhesives are also subject to "cold flow" and will penetrate the pores of the paper [15]. This makes it more difficult to reverse the tape over time.

Burgess [39] also evaluated the Chemical changes during accelerated aging of group of tapes that are often monitored by pH measurements and brightness change. those tapes showed an average decrease in pH of 0.5 units, and also the brightness changed between pale and dark yellow [36, 39].

4.3. Effect of aging on tape carriers or backings

Some of the unstable pressure-sensitive tape, such as cellophane, cellulose acetate and polyvinyl chloride, can undergo heat and light-catalyzed oxidation, which results in discoloration, and change in tensile strength, and the production of volatile secondary products, which causes shrinkage and stiffening of the plastic and impregnates crepe papers such as masking tapes which are saturated with an elastomer compound. Accordingly, the Components of the rubber-based adhesive may migrate upwards into the impregnated crepe paper, so it is susceptible to degradation mechanisms similar to rubber-based adhesives [36].

5. Aspects of deterioration caused by pressure-sensitive tape

5.1. Color change and yellowing of adhesive

The color change occurs after the induction period and exhibits a distinct increase in the degree and rate of the discoloration [35] as shown in Fig. 2 [40]. Brown spots and paper transparency [41]: The brown color indicates that the adhesive has chemically become part of the paper [42]. Paper transparency refers to the penetration of the adhesive, resins, and plastics into the paper fibers [22], these components deteriorate, oxidize, crosslink and form peroxides [43] for example, wood resins that were oxidized and change color to brown upon aging and develop small crystals in the adhesive that the critical eye can see. [36].

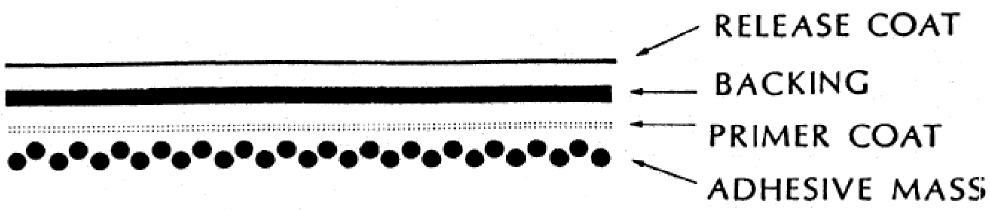

Fig. 1. Layers components of a typical pressure-sensitive tape [15]

5.2. The viscosity of the adhesive and its oiliness(Leroux,2016)

The viscosity of the adhesive begins and increases during the induction period then the viscosity weakens in the second stage of deterioration [35].

5.3. Hardening and brittleness of the adhesive

It occurs in the final stage of deterioration, in which oxidation increases and cross-linked adhesive. Then the hydroperoxides or highly oxidizing substances began to degrade and break down into volatile 'oxidation products' such as carbon dioxide, water, formaldehyde, formic acid, and other small-molecular fragments of the original chemical substances [35, 36].

5.4. The paper embrittling, breaking, tearing, undulating, and inks bleeding

In the final stage of adhesive deterioration when it occurs the adhesive becomes hard into the paper fibers, and the paper splitting occurs [17]. As a result of the difference in tensile strength between paper and carrier tape, the breaking or tearing can occur (Fig. 2) [40]; for example, cellophane which is a hygroscopic material tends to shrink if it is exposed to different degrees of temperature and different levels of humidity, the paper is breaking or tear due to the shrinking cellophane tape [36]. Another example is polyethylene carrier, whose its morphology is different from paper, under even a minimal thermo-hygrometric variation tends to move in differently way, creating tensions that can originate undulations [23]. Gorassini [40] reported that lossing of carrier or slipping occurs in the final stage of deterioration when the adhesive material loses its adhesive properties and turns into hard cross-linked bonds [15]. Bleeding of inks occurs as a result of interaction between the adhesive's solvent with the inks, causing alterations leading to chromatic variations and color migration (bleeding) (Fig. 3) [22, 23].

5.5. Paper acidity

It comes from acidic products that are absorbed from the tape. Rubber contains wood resin, thermoplastic acidic resin is susceptible to oxidation due to the presence of conjugated double bonds in its structure [36]. The cross-linked material has also contained a small number of peroxides leading to acid hydrolysis of the substrate and adjacent papers [20].

Fig. 2. Some forms of deterioration (hardness, brittleness, and discoloration) caused by pressure-sensitive tape [40]

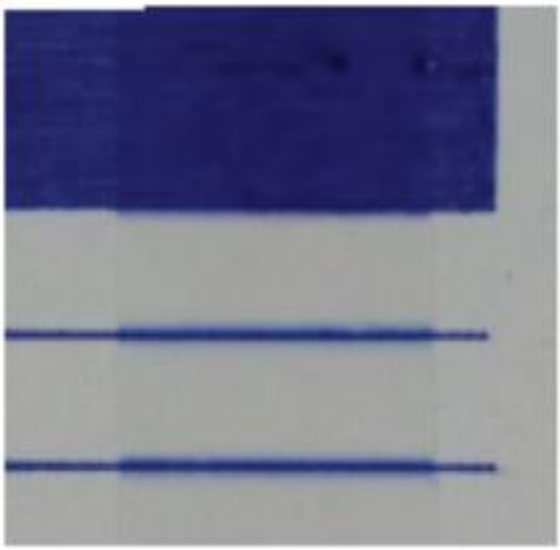

Fig. 3. Bleeding of inks as a result of interaction between the adhesive's solvent with the inks [23]

Fig. 4. Yellowing of the pressure-sensitive tape used to mend tears [44]

6. The deterioration mechanism of pressure-sensitive tape

The pressure-sensitive tape based on the rubber is subjected to deterioration over time. Feller [35] was one of the first researchers who talked about the deterioration of rubber, as he understood the nature of rubber deterioration through the mechanism of hydroperoxide formation. The deterioration process is described in three stages:

a. The oxidative induction stage

During this period, few chemical changes occur, the adhesive increases in viscosity [36], and the tape is relatively easy to remove (Tengelin,2017). After this period the hydroperoxides begin to form in the substance [35].

b. Oxidation stage

This stage is characterised by increasing oxidation and chain-scissions of the rubber polymer [20]. then The adhesive mass gets very sticky and oily. It also starts to be yellow . As a result of its oiliness, the adhesive mass can migrate and subsequent translucent in the paper adherend. Its components can also begin to affect certain media-particularly printing, typing, and ballpoint pen inks--causing them to bleed. In this stage, The adhesive can difficult be removed [15, 22].

c. Crosslinked stage

The adhesive, having permeated the paper; continues to oxidize, and gradually loses its adhesive properties. The carrier may fall off, and the adhesive residues crosslink, becoming hard, brittle, and highly discolored. Once it has reached this condition, the adhesive residue and the stain that has been created become very difficult, sometimes impossible to remove [15].

7. The removal of the pressure-sensitive tapes

7.1. Traditional Techniques for removal of the pressure-sensitive tapes

They are the common methods used in most libraries and restoration laboratories, such as a direct local application that combines mechanical removal with the use of solvents.

7.1.1. Mechanical cleaning

Mechanical dry cleaning can be used as a single cleaning technique or the first step in a more complex intervention. It is preferable to start with mechanical techniques over water techniques because dirt can be transferred by water to the paper fibers and fixed there if it is not removed before the aqueous treatment [45, 46].

The carrier is removed first to leave the adhesive layer intact to facilitate access for further dry or water-based treatment [42]. Dry techniques use of gentle heat with great care by the conservator, sandpaper, scalpels, erasers, etc. The heat-induced on the surface of the collotype allows it to separate from the paper and softens the adhesive, making it easier to remove with tweezers. Sandpaper, scalpels, or erasers such as the vinyl Fabercastell magic rub are used to remove the remnants of the active adhesive.

It should be noticed that the disadvantages of this process are summarized in the following points:

- The increasing temperature during this process allows the adhesive to penetrate the paper fibers, and staining of the paper can be obtained.
- The use of sandpaper or erasers can cause tears, wrinkles, or abrasion in the paper fibers. The abrasion leads to the deformation of the document [45-48].

7.1.2. Cleaning using solvents

Solvents are important materials for conservators. If used carefully they can achieve great results [17, 49]. Some risks can be obtained by using solvents. Some of these risks are as follows:

- There are associated risks, such as causing lateral movements of the decomposition products in the paper, which leads to the appearance of tide lines in the treated area.
- Some solvents can leave an oily residue on the paper
- Solvents can soften binders in ink or the paint media and cause ink bleeding.
- Solvents can reduce the natural moisture content of paper fibers at the molecular level.

Accordingly, the selection of the solvent is very important to detect the solvent that will be able to solve the adhesive. The solvent selection should be according to the Teas chart (Fig. 5) [50]. He also designed a novel paper glue remover (Gr) consisting of organic solvents 56% (v/v) dichloromethane/ normal hexane, for removal of pressure-sensitive adhesives consisting of polymer (t-butyl acrylate) from aged paper. Smith [15], Tengelin [20], Burgess [39], and Lannig [51], had discussed the removal of different pressure sensitive tapes from a paper by the use of the appropriate solvents as follows:

- Filmoplast P and Filmoplast P90 tapes can be easily removed by water after a short time from their application, but they can be difficult to remove using xylene, toluene, or acetone after natural aging.
- Archival Aids Document Repair Tape can be easily removed after a short time of its application using cyclohexane, and after aging, the adhesive can be removed using xylene or toluene.
- Magic Mending Tape can be removed using toluene, or a mixture of toluene and ethyl acetate. This mixture can swell the adhesive which can then be removed by scraping or combining of heated toluene and isopropyl alcohol.
- Masking Tape can be removed with petroleum benzene and toluene. After aging, it can be removed effectively by toluene, acetone, tetrahydrofuran, and N, N, dimethylformamide.
- Cellophane Tape is removed after a short time from its application using hexane, cyclohexane, petroleum benzine, and ethyl alcohol. After aging, it can be removed by methyl ethyl ketone, acetone, methylene chloride, tetrahydrofuran, N, N, dimethylformamide, and ethyl alcohol.

Other local application methods include treatments with a poultice, exposure to solvent vapors or treatment on a suction table. These treatments are characterized by introducing the solvent into the paper in a special controlled manner. As with the direct local application, the solvent may carry the dissolved substance into the paper fibers and this leads to the appearance of tidelines [17].

The advantage of working on the suction table is that it eliminates the need for mechanical removal [20]. It is a slow treatment for the treatment by exposure to solvent vapors, it is a slow treatment. It is a solvent chamber, which consists of a small glass container containing a blotter moistened with the solvent mixture fixed tightly to the base of the container as shown in Fig. 6 [51].

The oldest and most common cleaning technique is A poultice, considered the most important one. It consists of two parts: the first is a solvent to dissolve the adhesive, and the second is an absorbent that acts as a carrier for the solvent and can hold the solvent at the paper's surface for an extended period. Poultice's use is based on capillarity and water movement theories in the paper [52]. The disadvantages of the poultice are the possibility of depositing remains of the absorbent material into the paper fibers and forming a tideline.

Common absorbent materials consist of clays such as Fuller's earth, diatomaceous earth siliceous materials, starch paste [16, 53], and cellulosic materials such as cellulose powder [54] or blotters [55] or Methyl cellulose [52], cellulose ethers [53, 56] such as cetyl-hydroxy-ethylcellulose (PolySurf 69 TM CS) loaded whit 50:50 vol% mixture of the ethyl acetate: ethanol, which proved successful in dissolving the adhesive of pressure-sensitive tape [51]. Also, poultices are often loaded with enzymes to remove starch adhesives [57-58].

7.1.3. The immersion and humidification techniques

There are also integrated treatments that include immersion and humidification techniques. The immersion technique is the most effective method for removing tapes if the media and paper are not sensitive to water or solvents [16]. However, many solvents can dissolve some media and inks. The only stable solvent for inks and media is cyclohexane [23].

The immersion technique is fast and eliminates the risks associated with mechanical abrasion and tidelines. Moropoulou and Zervos [59]; and Isca et al. [60] investigated the effect of aqueous treatments on the strength of paper. The immersion treatments caused changes in the mechanical properties of paper which are correlated with slight changes in the diameter of the cellulose fibers due to their swelling by water molecules.

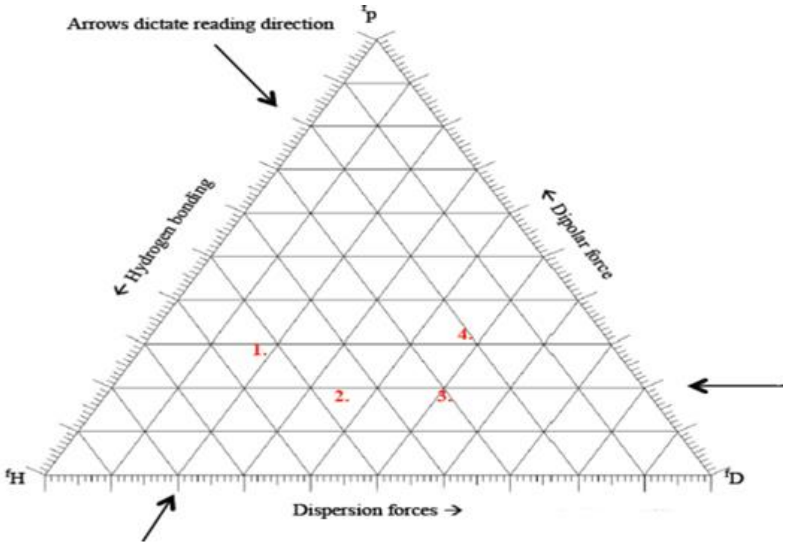

Fig. 5: Teas chart. The triangular chart makes it possible to calculate the molecular interaction according to the hydrogen bonding (fH), dispersion forces (fD), and dipolar forces (fp). Marks 1-4 represent solvents: 1. Water, 2. Ethanol, 3. Ethyl acetate, 4. Acetone [20].

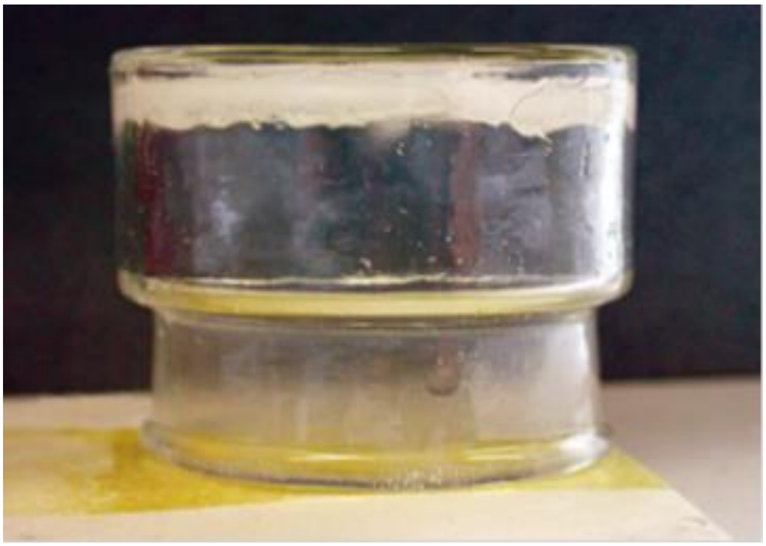

Fig. 6: The solvent chamber is inverted over the adhesive area [51]

The Humidification technique involves making the object moist or damp by the introduction of water in either the vapor phase (either cool or warm water vapor such as Gore-Tex) or in the liquid phase such as spraying [36].

7.2. Advanced Techniques for removal of the pressure-sensitive tapes

7.2.1. The use of poultice gels

Gel: is a water-based formulation thickened with a polymer or other high molecular weight material, is a vehicle for carrying the "active" cleaning components to the surface to be cleaned [61]. There are various of ways to classify gels, such as natural gel or synthetic gel according to the source; hydrogel or organogel according to the liquid medium in the polymer network; and chemical or physical gels according to their cross-linkage [62] (Table 1). Some of the types of gel used to clean paper are Rigid Polysaccharide Gels such as Agarose and gellan gums [63], chemical organogels based on Poly(methyl methacrylate) (PMMA) [23], and chemical hydrogels based on poly(2-hydroxyethyl methacrylate) (PHEMA)/ polyvinylpyrrolidone (PVP) [21].

7.2.2. Agar, or agarose gel

It consists of agarose, which forms approximately 70% of the mixture and agaropectin. is a rigid gel derived from the cell walls of a species of red algae of the Gelidium or Gracilaria families. It is readily soluble in hot water, stable in a relatively extended pH range, and (prior to adding other materials) is a safe, non-toxic, and eco-friendly material [18, 64]. Structurally, it is a linear polymer consisting of alternating D- galactose and 3,6-anhydro-L-galactose units [65] (Fig. 7). The gel porosity depends on agarose concentration and can be loaded with a water-based cleaning system (enzymes, chelating agents, surfactant solutions) [66]. Agar was also used as a solvent gel [64]. Tengelin [20] used agar as a solvent gel to remove pressure-sensitive labels from paper-covered half bindings: the solvent used was ethanol, 1:1 acetone: ethanol, and ethyl acetate. While all of the removals were considered somewhat effective, the ethyl acetate agar gel gave the best results with the least damage to the surface layer of the paper [20]. Warda [18] evaluated the use of agarose, carbopol, and laponite gel for the local removal of moisture-sensitive adhesives on paper artifacts, and the best results were obtained from agarose. He also confirmed that both Carbopol and Laponite contribute to the discoloration of paper after aging.

7.2.3. Gellan gum

It is a linear anionic heteropolysaccharide produced by Pseudomonas elodea, it is biodegradable and non-hazardous [67]. Its structure is based on a tetrasaccharide repeating unit composed of (1-3)-β D-glucose, (1-4)-β-D-glucuronic acid, (1-4)-β-D-glucose, and (1-4)-α-L-rhamnose as the backbone [68]. Gel formation is influenced by temperature, concentration, and thickness of the cast layer and by the presence or absence of mono or bivalent cations. Gellan gum is available in two grades: high and low acyl content, which form soft and hard gels respectively (Fig 9) [69]. Gellan has been widely used in the cleaning of paper artifacts either to remove stains, bleaching or as deacidification [70, 71]. Gellan gel acts as a molecular sponge. It was loaded with antifungals such as titanium dioxide nanoparticles to remove the foxing and mold stains [72, 73]. It is also loaded with enzymes to remove some adhesives [70, 74]. When it was used with solvents, it work as solvent gel [19] loaded it with methanol, ethanol, or 2-propanol to remove Scotch Magic 810# from paper.

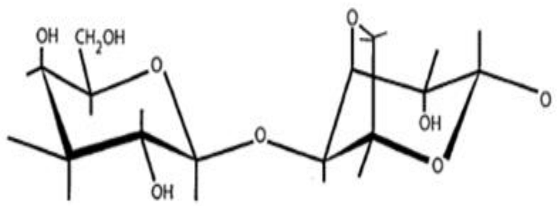

Fig. 7: Agarose repeat unit [18]

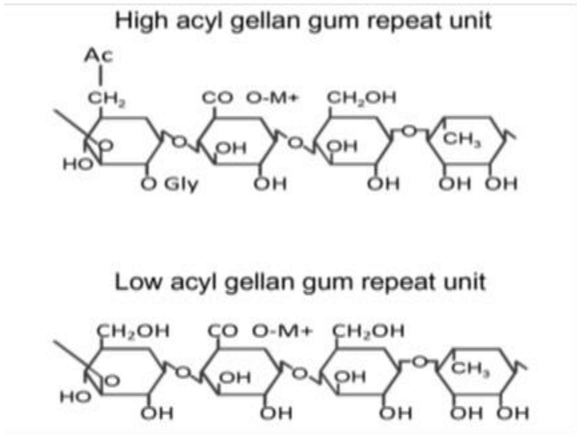

Fig. 8. Gellan gum structure [69]

7.2.4. Organogels

Organogels a hydrophobic polymer usually forms the structural network and they are used for the removal of polar water-insoluble materials [62, 66]. Organogels based on the crosslinking of poly(methyl methacrylate) and poly(ethyl methacrylate) loaded with diethyl carbonate(DEC) have been developed, as a new removal system, made of gel and a non-toxic

Table 1. Classification of polymer gels [62]

Swelling medium	Solid–liquid	Hydrogel	Water
		Organogel	Organic solvent
		Liogel	Oily solvent
		Alcogel	Alcohol
	Solid–gas	Xerogel	Air
		Aerogel	
	Solid–solid	Polymer–gel polymer	
		Gel–gum	
Constituent polymers	Natural gel	Protein gel, polysaccharide gel	
	Synthetic gel	Organic polymer gel, inorganic gel	
	Hybrid gel	Polysaccharide and synthetic polymer	
		Protein and synthetic polymer	
Cross-linkage	Covalent bonding Molecular interaction	Coulombic interaction	
		Hydrogen bonding Coordinate bonding	

solvent [22-24], Polyacrylic acid (PAA) was introduced in the restoration practice by Richard Wolbers in the late 1980s. PAA chains unfold at alkaline pH, forming extended 3D networks that increase the viscosity of the solution. When alkaline surfactants are used to deprotonate PAA, the thickened solution acquires emulsifying and detergent properties [75]. DEC is a new green solvent, polar aprotic, its constitutional formula is O=C(OCH2CH3)2 part of the family of alkyl carbonates [76] that constitutes a valid alternative to esters and ketones in most applications including the softening of natural and synthetic polymeric adhesives [77]. It is used to remove the pressure-sensitive tape from paper [22-24].

7.2.5. Highly Retentive Chemical Hydrogels

Highly Retentive Chemical Hydrogels Chemical hydrogels have a polymeric network constituted by covalent bonds, so they exhibit high water retention and control water release without leaving any gel residues on the artifacts [66, 78]. Semi-interpenetrating (IPN) poly (2-hydroxyethyl methacrylate)/polyvinyl pyrrolidone hydrogels " PHEMA/PVP" were synthesized and used for the removal of adhesives [79, 80]. By which organic solvents can be confined with structural and dynamic control at the nanoscale, termed "nanostructured fluids" (NSFs) such as (EAPC) [21]. It contains ethyl acetate and propylene carbonate water (more than 70% w/w) and is a surfactant, is a versatile o/w fluid able to swell and detach synthetic polymer coatings [21]. It gives good results in removing the Pressure-sensitive tape.

7.3. laser cleaning

The conventional dry and wet cleaning approaches are used on old masterwork only when strictly essential for its recovery. This prompted exploring the potential of the laser ablation as an advanced technique to address the complex cleaning problems of paper artifacts [81], and develop a laser system suitable for the accurate, efficient, and safe cleaning of paper objects. As well-known, a number of successful applications of the laser treatments to Manuscripts and other organic materials have been used [82-83].

It should determine the optimal laser parameters (wavelength, pulse duration, repetition frequency, energy density, laser spot dimensions, overlap, etc.) which are necessary for efficient treatment [17]. Scholten [17] studied the effect of two types of laser: Nd: Yag the green laser at 532 nm and Lambda Physik Compex 205 excimer laser at 248 nm to remove pressure-sensitive tape stains from paper artifacts and the effect of the laser on the properties of paper. The results showed that no detectable short-term chemical changes or visible discoloration are observed when using 532 nm (Nd: YAG's 2nd harmonic). This result was confirmed by Ciofini [81] who explained that the use of the second harmonic of the QS Nd: YAG laser (532 nm) equipped with an optical fiber beam delivery allowing for controlled energy release to the target has allowed achieving significant results in the removal of the foxing and mold stains from the old paper artifact. Nevertheless, Balakhnina [84] reported that the Pulsed laser irradiation at 532 nm and pulse energy of 340 mJ, causes a visible decrease in discoloration of old paper, after 5 years of natural aging, which can be due to laser ablation or photochemical reactions. Zekoum [85] reported that the exposure of paper to UV light with a wavelength less than 340 nm, can lead to photolysis or to photo-oxidative degradation of paper.

8. Conclusion

The use of pressure-sensitive tapes is one of the major problems in the improper restoration of manuscripts and historical documents. The structure of the pressure-sensitive tape consists of four layers. These layers are the adhesive mass; the backing, or carrier; the primer coat; and the release coat layer. The natural aging process affects the tapes and can lead to color change and yellowing of adhesive; increasing the viscosity of the adhesive and its oiliness; hardness and brittleness of the adhesive; brittleness, breaking, tearing, and undulating the paper; losing the carrier or slipping; bleeding of inks, and increase in the acidity of the paper. There are different techniques used for the removal of pressure-sensitive tapes. The traditional technique used mechanical cleaning, organic solvents, and immersion and humidification techniques. Many disadvantages can be obtained from traditional techniques such as abrasions resulting from the suing mechanical cleaning tools. The binders of the ink of paint media can be softened by solvents used and lead to the ink bleeding. Some solvents can leave an oily residue on the paper and cause staining. Different gels are the most common method used to remove pressure tapes such as poultice gels, Agar, agarose gel, gellan gum, and Organogels. Laser cleaning at 532 nm and pulse energy of 340 MJ, were used to remove the old tapes. It causes a visible decrease in the discoloration of old paper. The advanced techniques are safe, and fast, and remove the remains of pressure-sensitive tape residues.

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