Sourcing Local Materials for Proper Storage of Photographs in Egypt: An Investigative and Analytical Study

دراسة استقصائية تحليلية للوصول للمواد المتوفرة محلياً المناسبة لحفظ الصور الفوتوغرافية في مصر

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Abstract:
Photographs are an essential part of the Egyptian cultural and visual heritage. Institutions worldwide are making great efforts to preserve valuable photographs for future generations. Proper enclosures are important preventive measures to protect photographs from physical damage, stabilize sensitive materials, and act as a barrier between them and a potentially unstable environment. However, considering the economic changes Egypt went through in the past years, it is important to find proper solutions to fit the limited budgets of institutions. The authors searched for possible materials in the local market. Several samples of paper, cardboard and plastic materials were collected for testing their suitability for photograph preservation based on the internationally accepted standards. Finding appropriate local materials would benefit many countries in the Middle East that are facing a similar challenge. Evaluation was performed using visual inspection, microscopic inspection by digital microscope, ultraviolet light examination, flame test, polarization test, colorimetric measurements, Fourier transform infrared spectroscopy, pH value measurements, mechanical properties, and thickness measurements. Based on the obtained results, Cochet paper should not be used since it contains optical brighteners; cellophane is not recommended for storing photographs; and Bristol paper, Rigoletto paper, the local corrugated board, the local Nasibian, and the white foam board have pH values above 8 making them suitable for housing photographs excluding certain types of photographs (e.g., albumen prints and cyanotypes) since they are sensitive to alkalinity. In conclusion, Canson paper, imported Nasibian cardboard and polyester are safe for housing photographs, and are of regular availability and reasonable price.

Keywords: Housing materials, photographs, microscopic inspection, FT-IR, colorimetric measurements.

الملخص:
تشكل الصور الفوتوغرافية جزءًا أساسيًا من التراث الثقافي والبصري المصري. تبذل المؤسسات في جميع أنحاء العالم جهودًا كبيرة للحفاظ على الصور القيمة للأجيال القادمة. وتعد الحوافظ المناسبة تدابير وقائية هامة لحماية الصور الفوتوغرافية من التلف الفيزيائي، كما أنها تساعد علي استقرار المواد الحساسة، وتعمل أيضا كحاجز بين الصورة الفوتوغرافية والبيئة غير المستقرة المحتملة. ومع ذلك، نظرًا للتغيرات الاقتصادية التي مرت بها مصر في السنوات الماضية، فمن المهم للغاية إيجاد حلول مناسبة لتناسب الميزانيات المحدودة للمؤسسات. بحث المؤلفون عن مواد محتملة في السوق المحلية. وتم جمع العديد من عينات الورق والكرتون والمواد البلاستيكية لاختبار ملاءمتها لحفظ الصور الفوتوغرافية بناءً على المعايير المقبولة عالمياً. إن العثور على مواد محلية مناسبة من شأنه أن يفيد العديد من البلدان في الشرق الأوسط التي تواجه تحديًا مماثلاً. تم إجراء التقييم باستخدام الفحص البصري، والفحص بالميكروسكوب الرقمي، والفحص بالأشعة فوق البنفسجية، واختبار اللهب، واختبار الاستقطاب، وقياس التغير اللوني، والتحليل بالأشعة تحت الحمراء، وقياس قيمة الأس الهيدروجيني، وقياس الخواص الميكانيكية، وقياس السمك. وبناءً على النتائج التي تم الحصول عليها، لا ينبغي استخدام ورق

الكوشيه لأنه يحتوي على مبيضات بصرية؛ ولا ينصح باستخدام السيلوفان لتخزين الصور الفوتوغرافية؛ وورق البريستول وورق الريجوليتو والكرتون المموج المحلي وورق الناسيبيان المحلي وألواح الفوم الأبيض لها قيم أس هيدروجيني أعلى من ٨ مما يجعلها مناسبة لحفظ الصور الفوتوغرافية باستثناء أنواع معينة من الصور (على سبيل المثال، صور الألبومين والسيانوتيب) لأنها حساسة للمواد القلوية. وفي الختام، فإن ورق الكانسون واالناسيبيان المستورد والبوليستر آمنة لحفظ الصور الفوتوغرافية، وهي متوفرة بشكل منتظم وبأسعار معقولة.
الكلمات الدالة: مواد الحفظ، الصور الفوتوغرافية، فحص ميكروسكوبي، التحليل بالأشعة تحت الحمراء، التغير اللوني.

1. Introduction

The preservation of photographic collections is significant. Although the history of photography is brief, it has an enormous influence on mankind. Many photo collections exist today worldwide [1]. Photographs are fundamental documentary tools and visual resources that document important moments, individuals, values, cultures, expressions, landscapes, social development, and ways of life throughout history [2]. These remarkable records exist in relatively large numbers compared to other forms of art and cultural heritage [3]. The origins of photography in its current form can be traced back to the early 19th century [4]. Since then, many photographic processes have been developed resulting in a great variety of photographic materials, both negative (e.g., calotypes, cellulose nitrate negatives, cellulose acetate negatives, wet plate collodion, and dry gelatin plates) and positive (e.g., salt prints, albumen prints, collodion prints, silver gelatin prints and chromogenic prints). There are many other processes; however, these are the most common in Egypt. Early photographs of Egypt remain witness to the evolution of photography in the Middle East and to a time long gone. Today, these images are held by archives, libraries, palaces, and museums across Egypt, from Cairo to Nubia exhibiting different conditions of preservation [5].

Generally, photographs have a layered structure consisting of a binder layer containing the final image material on a support material such as paper, glass or plastic.

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Other layers may be present such as a baryta coating, coatings, hand coloring or mounting materials [6, 7, 8].

Throughout Egypt, our photographic heritage is suffering from various degrees of deterioration and/or degradation caused by numerous deterioration agents (e.g., improper temperature and relative humidity levels, improper light levels, biological threats, improper handling and misuse, poor storage and display, disasters, etc.) [9]. The complexity and multiplicity of the elements that make up a photograph give them a unique physical and chemical that is mostly responsible for their long-term stability characteristics [10].

Among the most common deterioration agents affecting the permanence of photographic collections is poor-quality storage enclosures. Photographs, whether negative or positive, spend most of their lives in direct contact with enclosures [11]. Direct contact with poor-quality enclosures can cause photographs to yellow, discolor, or become brittle (i.e., chemical damage). Moreover, physical damage (e.g., creases, tears, scratches, and abrasions) can occur when enclosures of inadequate size or shape are used [12]. Housing photographs in proper storage materials is a significant preventive measure that protects photographs from future damage by limiting exposure to dust, acids, atmospheric pollutants, mishandling and physical stresses that can damage them over time [13]. A careful selection of high-quality and well-designed enclosures can greatly prolong the lifespan of photographic materials [11]. Enclosures are specifically

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[12] Northeast Document Conservation Center. 2024. Session 3: Caring for Collections. https://www.nedcc.org/preservation101/session-3/3storage-enclosures [accessed 15/8/2024]

[13] Lavédrine, B. 2003. A Guide to the Preventive Conservation of Photograph Collections, USA: Getty Publications.

crucial if the collection contains color photographs, nitrate films, or early safety films [14]. Mainly, there are two materials used for housing photographs: paper and plastics [15].

The main component of paper is cellulose, a polysaccharide consisting of at least 500 glucose molecules [16] that are linked together by β-1,4-glycosidic bonds [17]. Originally, paper was made from cellulose sourced from linen and cotton rags [18] by a process that largely preserved the long fibers of the raw material. Starting in the mid-19th century, wood replaced rags as the raw material for paper manufacture [19]. Wood-derived fibers are mainly composed of cellulose, hemicelluloses, and lignin, but paper composition can also include additives [20]. The two main chemical pathways of paper degradation are acid-catalyzed hydrolysis and oxidation [18, 20, 21, 22]. The hydrolysis of cellulose involves the breakage of the β(1→4) bonds between particular D-glucose units, resulting in cellulose degradation, during which polysaccharides are degraded to form oligosaccharides and monosaccharides. The shortening of the cellulose chain is expressed in terms of decrease in its degree of polymerization (DP). Depolymerization of cellulose through hydrolysis results in a loss of the mechanical strength of paper [23]. The hydrolytic process of glycoside bond breakages is accelerated by the increase in

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the hydronium concentration in an acidic medium [24]. Sources of acidity include air pollution, poor-quality enclosures, the raw material itself (i.e., wood-pulp), manufacturing additives (i.e., alum-rosin sizing), and deterioration products (e.g., carboxylic acid) [25]. Oxidation of cellulose leads to the formation of aldehydes, ketones and carboxylic acids (i.e., carbonyl groups) which leads to discoloration. This is accompanied by the breakage of the glycosidic bonds, which contributes to the lowering of the degree of polymerization [26]. Hydrolysis and oxidation have a catalytic effect on each other. The formation of carbonyl groups weakens the glycosidic bonds making them more prone to hydrolysis. Moreover, water, a byproduct of cellulose oxidation, serves as a catalyzing agent for hydrolysis allowing for the transport of protons, radicals, and oxygen active forms within the paper structure [23], [27]. Hydrolysis, on the other hand, creates new reducing end-groups (i.e., –CHO) which are prone to oxidation [23]. By-products of paper degradation include: gluconic acid, mannonic acid, arabinonic acid, aldonic acid, furanosidic acid, isosaccharinic acid, metasaccharinic acid, lactic acid, 2-C methylglyceric acid, levulinic acid, acetic acid, and formic acid. Lignin and hemicelluloses are more susceptible to oxidation and hydrolysis compared to cellulose [28]. The chromophores in lignin with conjugated aromatic rings and carbonyl groups decompose into yellow-colored ketones and quinones upon absorbance of light, causing paper to yellow. Moreover, these molecules act as secondary chromophores which stimulate further yellowing and degradation [29]. Lignin degrades to form acidic compounds; these acids cause paper to rapidly degrade, eventually leading to total disintegration [30], [31]. Acidic enclosures may transfer acids to the enclosed photographic

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material causing embrittlement, discoloration and may increase the rate of deterioration [31, 32].

Plastics are composed of one or more polymers alongside additives such as plasticizers. Plasticizers ease the processing of synthetic and semi-synthetic polymers [33]. Plastics degrade at a slow rate; nevertheless, they are affected by the surrounding environmental conditions which cause the oxidation and chain scission of polymers, leading to changes in chemical composition, appearance, color, texture, physicochemical properties, and mechanical properties of the plastics [34]. Alongside chemical reactions that alter the polymer (e.g., oxidation, hydrolysis, and photolysis), additive migration is a degradation pathway common to multiple plastic types, which can result in significant damage or vulnerabilities. Migration of plasticizers occurs due to exposure to a solvent, heat application, or due to changes to the molecular structure of the polymer or additive which modifies the strength of interaction between polymer chains and weakly bound low molecular weight additives at ambient temperature. Loss of additives, volatile and semi-volatile organic compounds, can cause visible and physical changes (i.e., loss of mechanical properties). Moreover, the appearance of surface deposits (i.e., exudates) can also result from additive migration. These can trap dust, adhere storage materials to the objects, and transfer to adjacent materials [33]. Plastic materials can also produce acids as they age [35]. Chemical degradation of plastics can result in yellowing [36].

In the past, improper selection of storage materials has caused severe damage in photographic collections due to the effect of harmful ingredients and harmful volatile organic compounds produced by the enclosures and adhesives that seal them [37].

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Glassine, a smooth, glossy, semi-transparent paper, yet, over time, it becomes acidic, brittle and yellow [38, 39]. Moreover, in damp conditions, it can stick to the housed photographic material. It can also damage the photographic binder in the form of indentations [39]. Glassine paper also contains plasticizers and is frequently sized with rosin. These ingredients cause the paper to become very brittle, thus does not provide the required physical support. The brown Kraft paper enclosures contain image damaging ingredients such as lignin, which generates destructive peroxides [40] and acids [41, 42]. These deterioration byproducts attack all the components of photographic materials causing the image final material (i.e., image silver or organic dyes) to discolor and they lead to the yellowing and embrittlement of the binder layer and supports, both the primary and the secondary supports [43, 44]. Untreated wood pulp paper contains sulfur which causes image silver to decay [44]. In general, paper containing lignin is considered a significant factor of image silver decay. Resulting symptoms are overall fading, silver mirroring, redox blemishes, discoloration, and staining [45]. Regarding plastic enclosures, many polymers are inappropriate for the preservation of photographs since they release deleterious products such as plasticizers, chlorinated and nitro compounds and acids. In the past, most enclosures were made of poly vinyl chloride (PVC) which is chemically unstable [46]. The main degradation processes of poly(vinyl chloride) (PVC) are elimination of HCl and plasticizer migration [47]. Formation of hydrochloric acid causes

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irreversible damage to photographs [39, 44]. The elimination of hydrogen chloride causes the formation of polyene sequences that function as chromophores, these are responsible for the yellowing of the plastic [48]. In brief, chemically unstable plastics produce by-products that accelerate the degradation of photographs as they deteriorate. Plasticizer migration involves the exuding of plasticizers from PVC under humid conditions; this leads to the deposition of sticky droplets on the photograph which can cause the plastic enclosure to stick to the photographic surface, a form of damage known as ferrotyping [49]. Under favorable conditions, PVC plasticizers can encourage fungus growth causing additional damage to the photographs [50]. Moreover, plastic enclosures tend to develop electrostatic charges increasing the likelihood of scratches [49].

Conservators use varying enclosures for safeguarding photographs including envelopes, sleeves, folders, interleaves, wrapping tissues and paper, albums and boxes **(Fig. 1)** [50]. Selecting between paper and plastic depends on the type of photograph being enclosed and on the surrounding environmental conditions [51]. Anyhow, both materials have advantages and disadvantages. The pros of paper enclosures are being opaque which allows for protection from light; being porous which prevents the accumulation of moisture and detrimental gases; being less expensive than plastic; and being easy to write on and label with a pencil. On the other hand, their cons are being difficult to view the enclosed photograph without removing it from the enclosure, this increases damage from handling, abrasion, and fingerprinting. Moreover, in case of an emergency, paper will not protect photographs against water or moisture damage. The advantages of using plastic enclosures are being transparent which allow the photograph to be viewed without the need to remove it from the enclosure, and this significantly reduces the chance of abrading, scratching, or fingerprinting the photograph. They also protect the photographs from agents such as moisture and sulfides present in the environment which react with all components of the photographs and accelerate their deterioration

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[52], [53], [54]. Regarding their disadvantages, plastics are more expensive and can create a static charge that might attract dirt and particulates, and lift and flake the photographic binder from the surface of the photograph. Additionally, they cannot be labelled with a pencil. Moreover, they can abrade and scratch photographs during insertion and removal; they can trap moisture and cause ferrotyping (i.e., stick to the photographic surface resulting in shiny areas); they can be soft requiring additional support; and plastics with low melting points (i.e., polyethylene) can melt during extremely high heat, adhering themselves irreversibly to the photographic materials stored inside them [55].

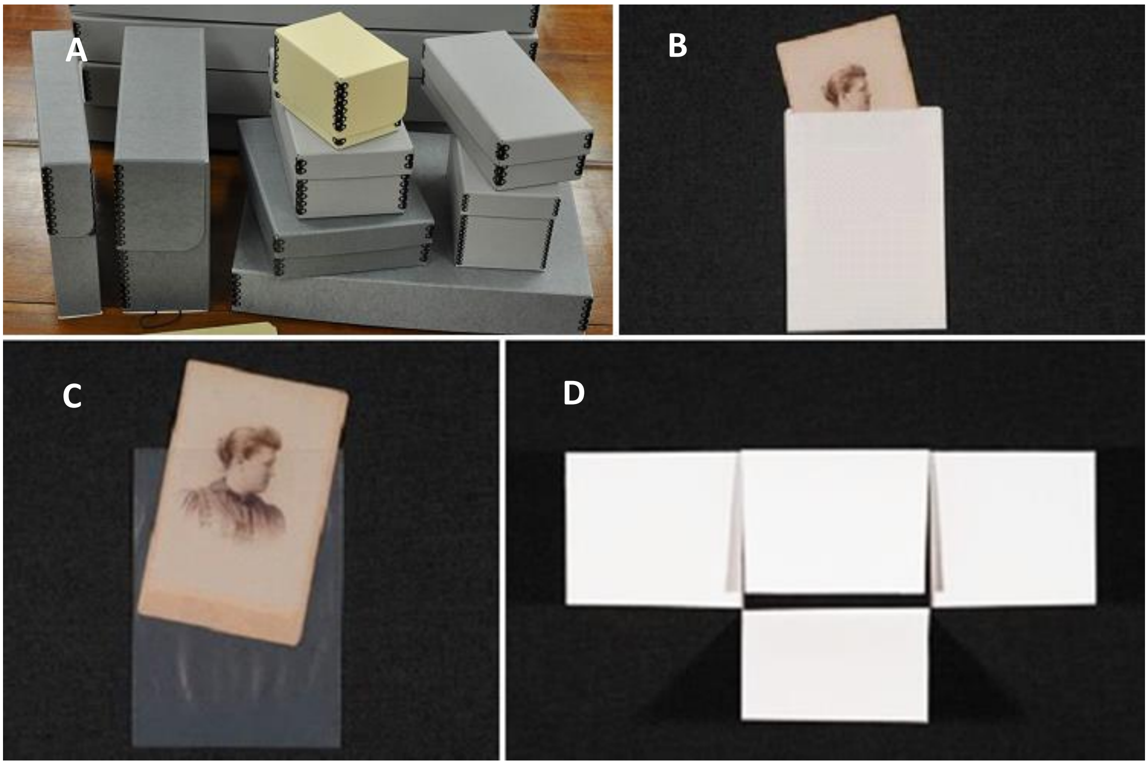

Fig. 1. Examples of enclosures used for housing photographic materials. A) Storage boxes, B) a paper envelope, C) a plastic enclosure, and D) a four-flap enclosure.
Source: https://www.pinterest.com/pin/416231190531268501/, and https://www.nedcc.org/assets/media/documents/Preservation%20Leaflets/5_6_Enclosures.pdf.

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[54] National Park Service. 1993. Storage Enclosures for Photographic Prints and Negatives, *Conserve O Gram*, 14(2). https://www.nps.gov/museum/publications/conserveogram/14-02.pdf [accessed 18/5/2010].

[55] Northeast Document Conservation Center. 2024. Storage Enclosures for Photographic Materials, Preservation Leaflet.https://www.nedcc.org/assets/media/documents/Preservation-%20Leaflets/5_6_Enclosures.pdf [accessed 12/8/2024].

There are seven International Standards (i.e., ISOs) and BS4971:2017 that specify the criteria for photograph enclosures. Generally, the following criteria should be met: it should not cause scratches and abrasions; it should be designed to be removed from the object and not vice versa; it should promote safe handling and easy access; it should not contain chemicals that may cause damage to photographs; it should have good aging characteristics; it should provide adequate protection as well as proper physical support and protection [56]. Both ISO 18902:2013 and ISO 18916:2007 provide specifications on enclosure formats, papers, plastics, adhesives, and printing inks [56, 57]. Based on these standards, paper should be high in alpha-cellulose (i.e., 87% or above), acid-free, lignin-free or low-lignin, sulfur-free (i.e., less than 0,000 8 %), peroxide-free, wax-free, dye-free, free from metallic particles and have neutral sizing [56, 57, 58]. Acid-free paper refers to both neutral paper (i.e., pH ranging between 7.0-7.5) and buffered paper (i.e., pH 8.5 or above) [59], the later contains an alkaline material, such as calcium carbonate, which neutralizes acids as they form. Buffered paper enclosures are not recommended for the housing of color images, cyanotypes, and albumen prints due to their sensitivity to alkalinity. Preferred papers and boards for photographic images are those made from cotton, linen, and wood pulp papers which have been treated to remove harmful chemicals (e.g., lignin) [57]. On the other hand, plastic enclosures should be free from plasticizers, slip agents, ultraviolet inhibitors, dyes, coatings or other materials that can break down leading to the deterioration of the enclosed photographs [57, 60]. There are three types of plastic that are recommended for housing photographs: polyester, polypropylene, and polyethylene. Polyester is the most inert and rigid of these plastics; yet it generates static electricity that can attract dust, and it is expensive. Polyethylene is less transparent, less rigid, most easily scratched, but it is less expensive [56, 59].

Nevertheless, the only way to be certain of the stability of enclosure materials for photographic materials is to purchase a material that has passed the Photographic Activity Test (PAT) [57]. The PAT is an International Standard: ISO 18916. The PAT

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[56] Finch, L. 2024. Photograph storage materials - What should you use?.https://www.preservationequipment.com/Blog/Blog-Posts/Photograph-storage-materials-What-should-you-use.

[57] Northeast Document Conservation Center. 2024. Storage Enclosures for Photographic Materials, Preservation Leaflet.https://www.nedcc.org/assets/media/documents/Preservation-%20Leaflets/5_6_Enclosures.pdf [accessed 12/8/2024].

[58] International Standard Organization. 2001. ISO 18902: Imaging materials — Processed photographic films, plates and papers — Filing enclosures and storage containers, First edition. https://law.resource.org/pub/us/cfr/ibr/004/iso.18902.2001.html [accessed 10/7/2024].

[59] National Park Service. 1993. Storage Enclosures for Photographic Prints and Negatives, *Conserve O Gram*, 14(2). https://www.nps.gov/museum/publications/conserveogram/14-02.pdf [accessed 18/5/2010].

[60] Canadian Council of Archives. 2003. Basic Conservation of Archival Materials: Revised Edition, Chapter 6: Collectionshttps://archivescanada.ca/wp-content/uploads/2022/08/RB-ch6_en.pdf [accessed 12/8/2024]

explores the possibility of chemical interactions between photographs and a given material after prolonged contact. It uses two detectors. One detector screens for oxidation and reduction reactions which can cause image decay. The other detector screens for chromophores, compounds that can cause yellowing of the support [61].

High-quality storage materials which conform to these standards are available through international suppliers; yet are very costly. Like many countries around the globe, Egypt faces an economic crisis, particularly with the weakening of its pound against the American dollar and the Euro. Consequently, importing high-quality materials that are suitable for the storage of photographic materials is not an option. What about the local market? The most important paper and cardboard manufacturers in Egypt are Qena paper industry Co., Rakta paper manufacturing company, Misr Edfu pulp, writing and printing paper company, National paper products company, Egyptian German company for paper industries, Simo, and the Islamic company for paper manufacturing. Between 2020 and 2023, the paper market witnessed a major crisis that has caused a significant hike in paper price, it almost doubled, with commodity shortages, energy prices, Brexit and surging freight costs feeding into rising prices. At the same time, significant growth in e-commerce – driven by national lockdowns – brought an overwhelming increase in home deliveries. However, a massive shift is expected in year 2024, since companies are expected to follow new methodologies to protect their businesses and respond to consumer and trade demands [62]. Nonetheless, the authors went searching for possible alternative materials in the local market, and found many, most are not made in Egypt; however, they are consistently available in the local market. All available sources of paper, cardboard and plastic materials have been surveyed, and several samples were collected for testing their suitability for photographic collection preservation (precisely, silver gelatin prints). Evaluation was carried out using visual inspection, microscopic inspection by digital microscope, ultraviolet (UV) light examination, flame test, polarization test, colorimetric measurements, Fourier transform infrared spectroscopy (FT-IR), pH value measurements, mechanical properties, and thickness measurements.

The main aim of this paper is to search for alternative storage materials in the local market that are suitable for housing photographic materials according to the generally accepted standards listed previously. It must be of good quality, regular availability and reasonable price. This would greatly benefit the preservation of visual heritage in Egypt and the Middle East who are facing the same challenge due to the economic situation

[61] Image Permanence Institute 2024. Photographic Activity Test, Rochester Institute of Technology/Image Permanence Institute, Rochester, NY, U.S.A. https://www.imagepermanenceinstitute.org/tests/pat.html [accessed 12/8/2024].
[62] Wall, C. 2023. Expert predictions for biggest 2024 trends in paper and packaging sector, Sustainable Packaging News. https://spnews.com/expert-predictions/ [accessed 15/4/2024].

in the Arab region. Implementing sustainable solutions to meet best practices for preserving photographic collections remains a global challenge [63].

2. Materials and methods

2.1. Materials

2.1.1. Enclosure material samples

Four different types of paper, four types of cardboard and two types of plastic sheets were tested as shown in **(Table 1)** and **(Fig. 2)**. The given names are commercial names known by the vendors. Eight samples were prepared of each material, one sample served as the control, three samples (i.e., nos. 2-4) were used for the before aging measurements and three samples (i.e., nos. 5-7) were used for evaluating the aging properties of the selected materials, and the final sample (i.e., no. 8) was used for studying how each material affected silver gelatin prints. The size of each sample is 2.5 cm × 10 cm.

Table 1 Tested paper, cardboard and plastic samples.

Sample type	Commercial name	Sample no.
Paper samples	Canson paper	**CP**
	Bristol paper	**BP**
	Cochet paper	**CHP**
	Rigoletto paper	**RP**
Cardboard samples	Local Nasibian	**LN**
	Imported Nasibian	**IN**
	Local corrugated (brown)	**LC**
	Foam board (white)	**FB**
Plastic Samples	Unknown flexible transparent plastic sheets	**FPL**
	Unknown stiff transparent plastic sheets	**SPL**

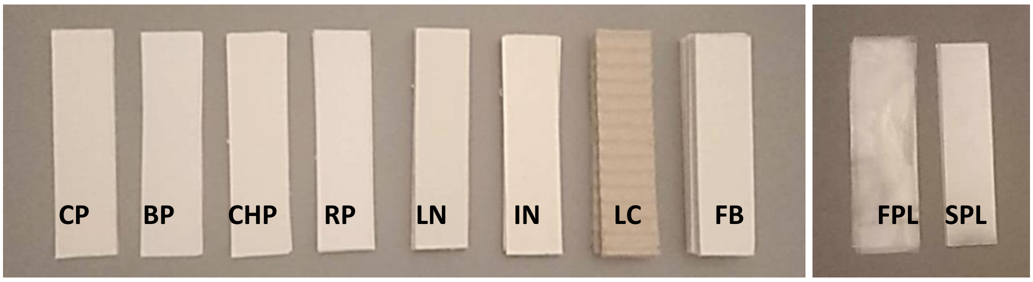

Fig. 2. Paper, cardboard and plastic samples.

2.1.2. Photographic samples

A Fomabrom Variant III 112 FB VC Paper with a matt surface finish was selected for the preparation of the silver gelatin fiber-based test materials, representative of the most commonly used photographic process for producing black-and-white photographs in the 20th century [64].

[63] Norris, D. and Gutierrez, J. 2017. Preventing destruction: preserving our irreplaceable photographic heritage, *American Art*, 31(1), pp. 18-23.
[64] Wagner, S. 2024. Gelatin silver prints. National Gallery of Art.

Basically, a silver gelatin print is composed of silver metal particles suspended in a gelatin layer on a primary paper support [65]. A fourth component which may be included is an inter-layer between the support and the image layer known as the baryta coating [66]. The baryta coating consists of finely ground white barium sulfate in gelatin [67]. An integral secondary support may be present. The most common form of integral secondary supports for prints is original mounts [68].

For sample preparation, a greyscale with ten different densities was contact printed on the photographic paper using a Durst M670 BW photographic enlarger. The samples were exposed for 50 seconds, and a 5 + 4 Jessop contrast filter was used. The samples were developed in Fomatol LQN for 2:15 minutes at a temperature of 24°C and fixed in a hypo bath for a period of 10 minutes. Washing proceeded for 20 minutes. The samples were allowed to dry, face up on a drying rack. For flattening, they were placed between blotting paper and pressed in a hydraulic press for 2 days. The chemicals used were prepared as follows: Fomatol LQN 250mL 1:7 (developer: water) at 25°C, hypo 250g in 1L of water at 25°C. Photographic samples were fixed to the selected storage materials to study how the later affects the former in terms of optical and chemical changes.

Three densities (each cut into a 1.5 cm^2 square) were selected for this study, one representing the highlights or D-min (i.e., 3), the second representing the midtones (i.e., 8), and the last representing the shadows or D-max (i.e., 48) **(Fig. 3)**. The samples were artificially aged following the ISO 5630-3:1996 standard listed below for a period of 10 days which is equivalent to natural aging for 50 years, to resemble historical photographs.

2.2. Accelerated aging

Paper, cardboard, plastic samples and photographic samples in contact with enclosure materials were first allowed to acclimate overnight in a climate-controlled room with parameters of 22°C samples ±2 and 50% RH ±5. Then, accelerated aging was applied on the samples in a closed climatic chamber at a temperature of 80°C and

https://www.nga.g-ov/research/online-editions/alfred-stieglitz-key-set/practices-and-process-es/gelatin-silver-prints.html [accessed 6/10/2024].

[65] Roosa, M. 2004. Handling and storage of photographs, *International Preservation Issues*, 5, the International Federation of Library Associations and Institutions (IFLA) Core Activity on Preservation and Conservation.

[66] Hendriks, K., Ross, L. 1998. The restoration of discolored black-and-white photographic images in chemical solutions, *Reprint from preprints of papers presented at the 16th Annual Meeting of the American Institute for Conservation of Historic and Artistic Works*, New Orleans, Louisiana.

[67] Hendriks, K. 1984. The Preservation and Restoration of Photographic Materials in Archives and Libraries: A Ramp Study with Guidelines, UNESCO, Paris.

[68] Reilly, J. 2005. Stability Problems of 19th and 20th Century Photographic Materials. Rochester Institute of Technology, New York. http://albumen.conservation-us.org/library/c20/reilly-stability.html [accessed 6/10/2024].

65% RH for a period of 2 days which is equivalent to natural aging for 10 years based on the conditions described in ISO 5630-3:1996 standard [69, 70, 71]. The test was performed in a Binder dry oven with digital indicator, model no. 92403000002000 at the National Institute of Standards (NIS), Giza, Egypt.

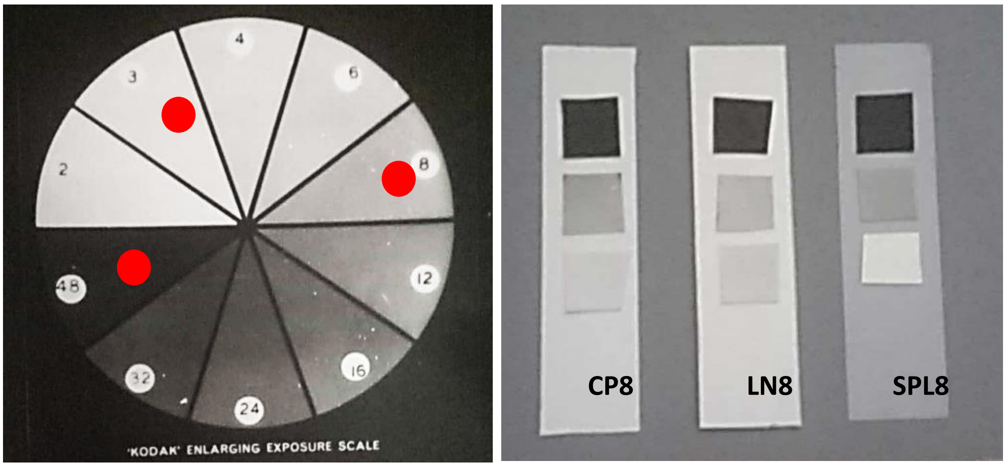

Fig. 3. Resultant photographic sample and areas selected for measurements, where 3 represents the highlights, 8 represents the midtones and 48 represents the shadow areas (left), and examples of the photographic samples fixed to the storage materials (right).

2.3. Assessment methods

2.3.1. Visual inspection

Visual observation is included to monitor visual changes. A photographic survey was carried out before and after artificial aging in ambient light.

2.3.2. Digital microscope inspection

A ROHS Digital USB microscope 1000X was used to document surface changes in tested samples before and after artificial aging. This procedure was carried out at the Conservation Department, Faculty of Archaeology, Cairo University.

2.3.3. Ultraviolet light examination

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[69] Pentzien, S., Conradi, A. and Krüger, J. 2011. The Influence of Paper Type and State of Degradation on Laser Cleaning of Artificially Soiled Paper. Radvan, R., J. Asmus, M. Castillejo, P. Pouli, and A. N1`evin (eds.), Lasers in the Conservation of Artworks VIII, London: Taylor and Francis Group, pp. 59 –65.

[70] Kamińska, A., Sawczak, M., Ciepliński, M., Śliwiński, G. and Kosmowski, B. 2004. Colorimetric study of the post-processing effect due to pulsed laser cleaning of paper, *Optica Applicata*, 34(1), pp. 121 –132.

[71] Royaux, A., Francke, I., Balcar, N., Barabant, G., Bollard, C., Lavédrine, B., and Cantin, S., 2017. Aging of plasticized polyvinyl chloride in heritage collections: the impact of conditioning and cleaning treatments, *Polymer Degradation and Stability*, 137. DOI: 10.1016/j.polymdegradstab.2017.01.011

UV light is an immediate examination tool which is non-destructive, easy to use, inexpensive, and requires only a dark room and protective glasses [72]. UV radiation was used to examine the paper and cardboard samples for optical brighteners [73, 74] which are not a recommended component in paper and cardboards used in contact with photographic materials [75]. Optical brighteners are molecules that absorb ultraviolet light and emit light in the visible range, brightening the substrate by emitting over 100% of the incident light. This causes the materials to appear whiter than white [76].

The UV radiation sources used are two F15W T8 BL350 Toughcoat™ Blacklight lamps from Sylvania, made in Germany, wattage for each lamp: 15 watt. These tubes emit UV radiation with a peak at around 350 nm. The sources were placed at a 20 cm distance from the samples.

2.3.4. Flame test and polarizing filters test

The flame test was used to identify the type of plastic used to manufacture the tested sheets. The test involves exposing the unidentified plastic sample on a hot copper wire to a benzene flame and notice the flame color as the type of plastic is identified based on the resulting color of the flame [77, 78]. The most recommended plastic material to be used with photo collections, polyester (e.g., Mylar), can be identified with two pieces of polarizing filters. Polyester when viewed between two crossed polarizing filters exhibits red and green interference colors like those seen on soap bubbles. The polarization test is a simple, non-destructive test that is used to differentiate between certain plastics [77].

[72] Hickey-Friedman, L. 2002. A review of ultra-violet light and examination techniques, *Objects Specialty Group Postprints*, 9, pp. 161-168.
[73] Messier, P., Baas, V., Tafilowski, D. and Varga, L. 2005. Optical brightening agents in photographic paper, *Journal of the American Institute for Conservation*, 44(1), pp. 1-12.
[74] Engelke, F. and Duran Casablancas, C. 2023. Optical Brighteners: Movement and Degradation in Paper. IADA 2023 Conference Poster.https://www.researchgate.net/public-ation/374229127_Optical_Brighteners_Movement_and_Degradation_in_Paper[accessed 3/10/2024].
[75] Library of Congress Preservation Directorate. 2024. Specifications Number 300-361 – 16 for Photographic Storage Box. https://www.loc.gov/preservation/resources/specificati-ons/specs/300-361_16.pdf [accessed 15/6/2024].
[76] Mustalish, R. 2000. Optical brighteners: history and technology, *Studies in Conservation*, 45(Supplement-1), pp. 133-136. DOI: 10.1179/sic.2000.45.Supplement-1.133
[77] Xu, T., 2020. The Identification of Plastics.https://www.researchgate.net/publicat-ion/350579609_THE_IDENTIFICATION_OF_PLASTICS/citations#fullTextFileContent. [accessed 3/10/2024].
[78] Fischer, M. 2020. Short Guide to Film Base Photographic Materials: Identification, Care, and Duplication, Northeast Document Conservation Center. https://www.nedcc.org/free-resources/preservation-leaflets/5.-photographs/5.1-a-short-guide-to-film-base-photographic-materials-identification,-care,-and-duplication [accessed 3/10/2024].

2.3.5. Colorimetric measurements

The change in color due to contact with selected storage materials and artificial aging was measured using an Optimatch 3100® spectrophotometer from the SDL Company. All samples were measured in a visible region, with an interval of 10 nm using D65 light source and an observed angle of 10 degrees. The CIELAB color parameters (i.e., L*, a*, and b*) were used, where L* defines lightness and varies from 0 (black) to 100 (white); a* represents the red/green axis, where +a means red and –a means green; and b* represents the yellow/blue axis, where +b means yellow and –a means blue. All values of L*, a*, and b* were obtained before and after artificial aging. Each reading was the average of three measurements [79]. The total color difference ΔE* was also calculated from the following formula: $\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})$ ½ [80]. The analysis was carried out at the National Institute of Standards (NIS) in Giza, Egypt.

2.3.6. Fourier Transform Infrared Spectroscopy (FT-IR)

FT-IR spectroscopy was used to study the chemical changes which may have occurred post artificial aging. The FT-IR instrument used is a Nicolet 380 FT-IR Spectrometer under absorbance mode. The analysis was carried out at the National Institute of Standards (NIS) in Giza, Egypt. The Essential FTIR software was used to process the obtained spectra.

2.3.7. pH value measurement

The pH value measurements were carried out using a Martini Mi 180 Bench Meter. The pH values were measured according to ASTM D778-97(2002) Standard Test Methods for Hydrogen Ion Concentration (pH) of Paper Extracts, the cold-extraction method. 0.5 g of each sample, before and after aging, were placed into 50 mL of distilled water for a period of 24 hours. The results reported are the average of five measurements. Measurements were carried out at the National Institute of Standards (NIS) in Giza, Egypt.

2.3.8. Mechanical properties

Mechanical behavior of the samples (i.e., tensile strength and elongation %) were studied using the dynamometer produced by SDL ATLAS, H5KT. The samples were cut in the machine direction to strips of 2.5 cm × 10 cm. The results reported are the average of three measurements. The measurements were carried out at the National Institute of Standards (NIS) in Giza, Egypt.

[79] Nemtanu. M. 2008. Influence of the electron beam irradiation on the colorimetric attributes of starches. *Romanian Journal of Physics*, 53(7-8), pp.873 –879.

[80] Kamperidou, V., Barboutis, I. and Vasileiou, V. 2012. Effect of thermal treatment on colour and hygroscopic properties of poplar wood, wood is good –with knowledge and technology to a competitive forestry and wood technology sector. *Proceedings of the 23rd International Scientific Conference*, University of Zagreb, pp. 59 -67.

2.3.9. Thickness

Thickness is an important factor to be considered for the paper, cardboard and plastic which will be used in preservation, particularly the preparation of enclosures. Different thicknesses are needed for various purposes. For this reason, thickness were measured for each sample with a portable digital thickness gauge, 12.7 mm Max Range, 0.01mm/0.0005" Accuracy, from SDL Atlas. The results reported are the average of three measurements. The measurements were carried out at the National Institute of Standards (NIS) in Giza, Egypt.

3. Results and discussion

3.1. Visual inspection

Visual inspection results showed no apparent changes in all paper, cardboard, plastic, and photographic samples excluding sample SPL which showed slight warping of the edges **(Fig. 4)**.

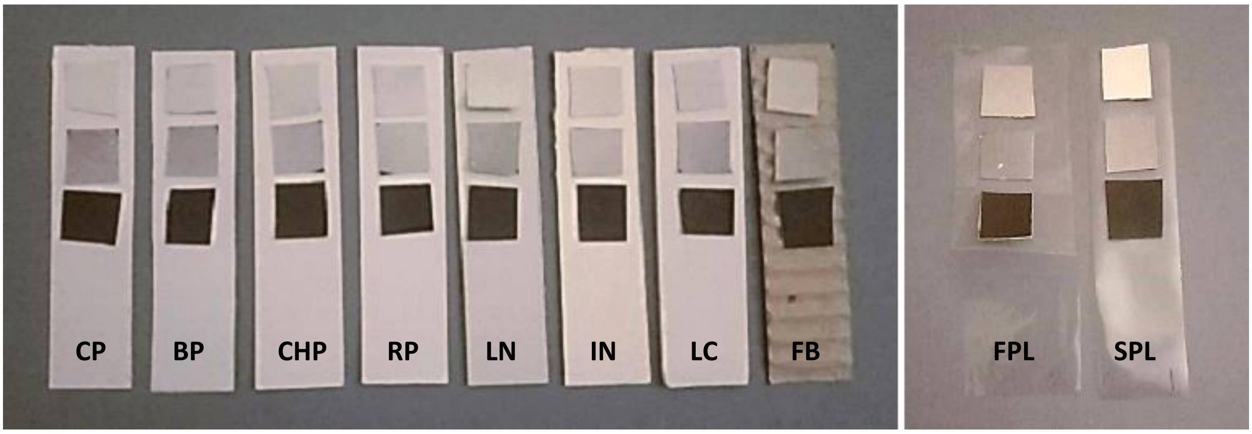

Fig. 4. The samples after artificial aging.

3.2. Digital microscope inspection

Paper and cardboard samples viewed under the digital microscope are shown in **(Fig. 5)** and **(Fig.6)**. Microscopic inspection also revealed the occurrence of extremely minor changes for the selected storage samples as well as for the photographic samples (i.e., D-min, midtones, and D-max) post artificial aging compared to the unaged samples **(Fig. 7)** and **(Fig. 8)**.

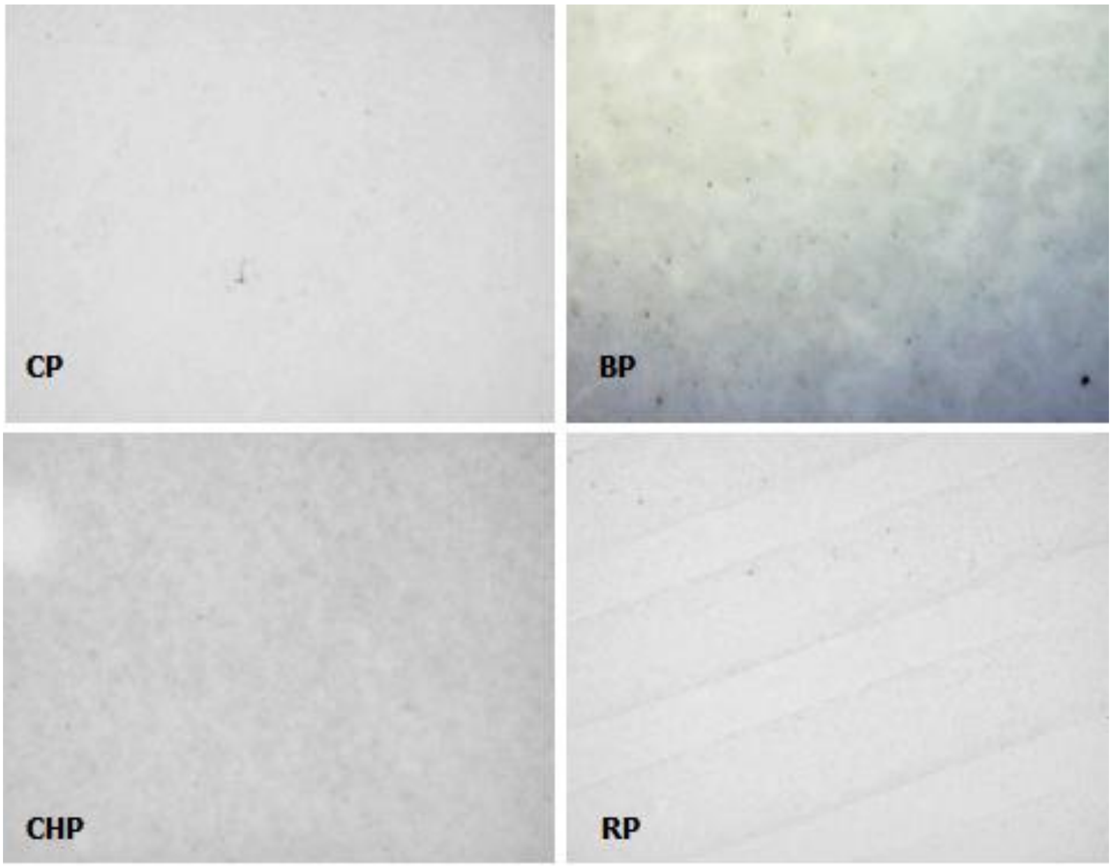

Fig. 5. Paper samples viewed under the digital microscope.

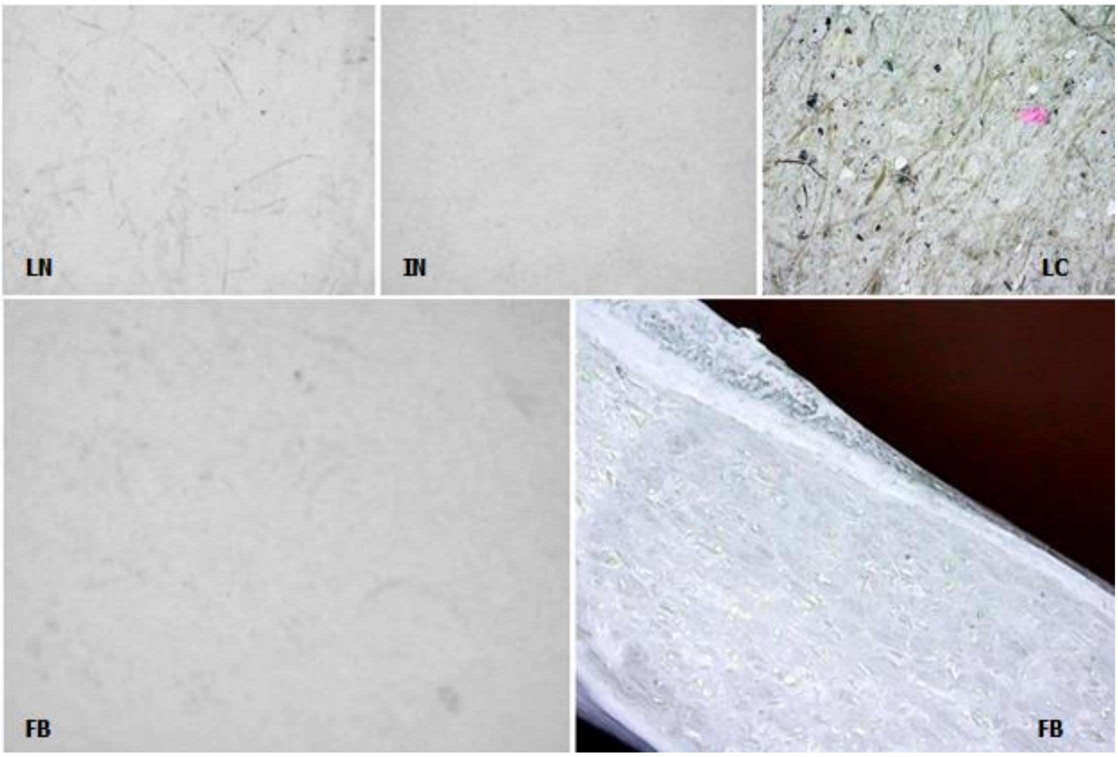

Fig. 6. Cardboard samples viewed under the digital microscope.

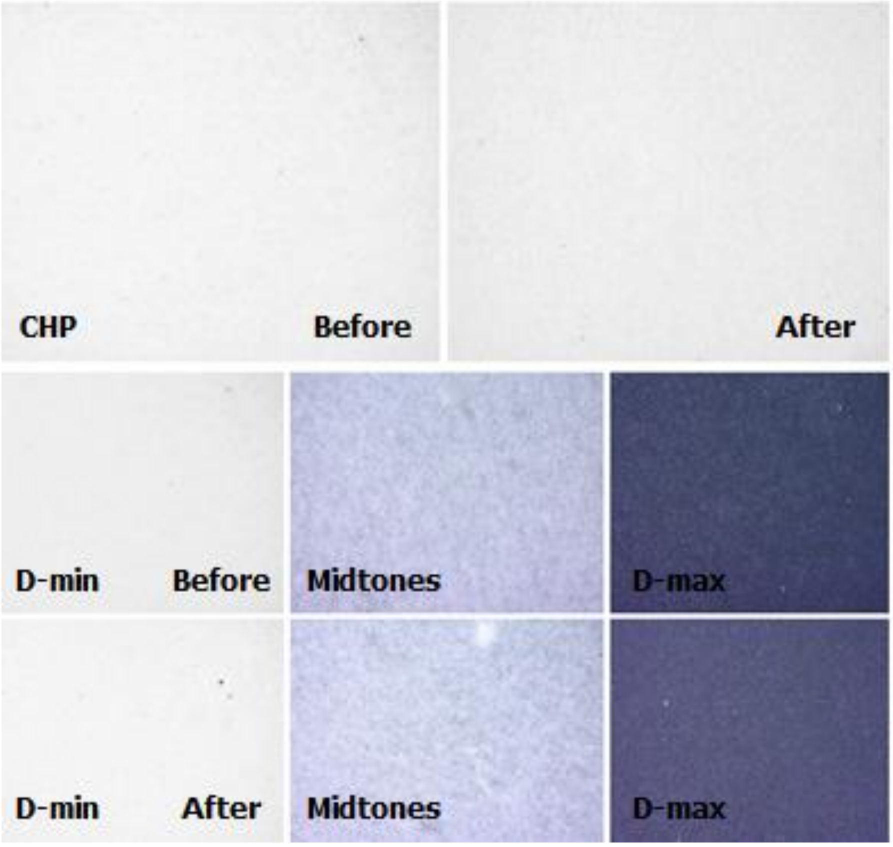

Fig. 7. Sample CHP and the tested photographic samples, before and after artificial aging.

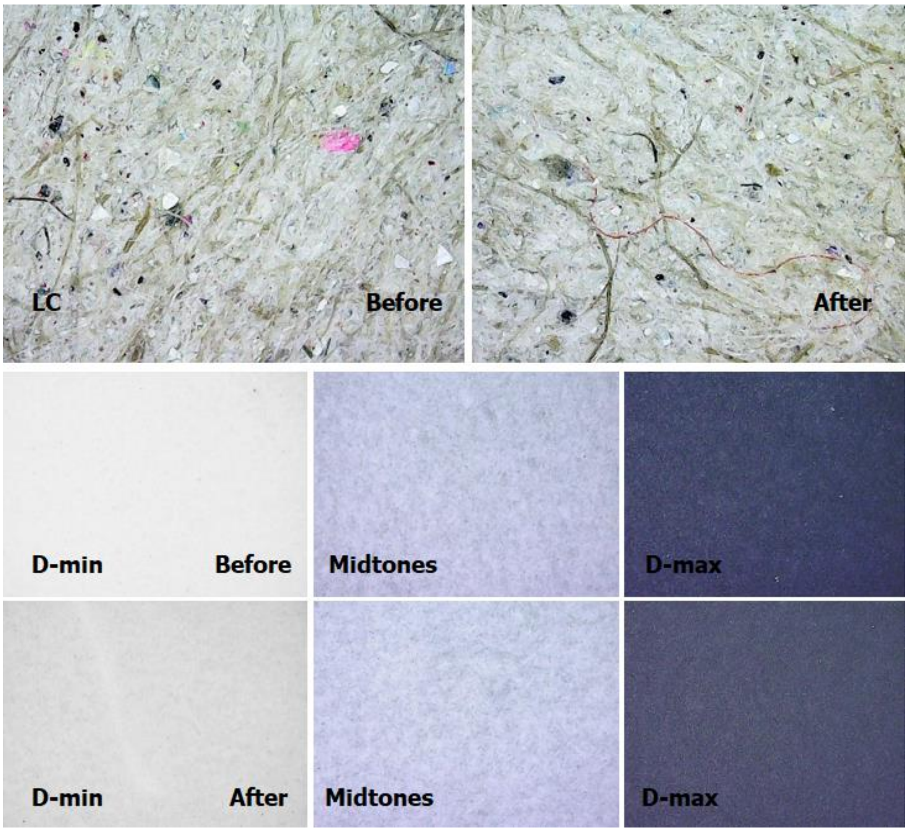

Fig. 8. Sample LC and the tested photographic samples, before and after artificial aging.

3.3. Ultraviolet light examination

Under ultraviolet light (i.e., emission wavelength 350-375nm), optical brighteners (OBs) should produce a bright blue fluorescence. However, if they are present at low concentrations, this result may not be detected [81]. Results did not reveal the presence of OBs for all samples excluding sample CP **(Fig. 9)**.

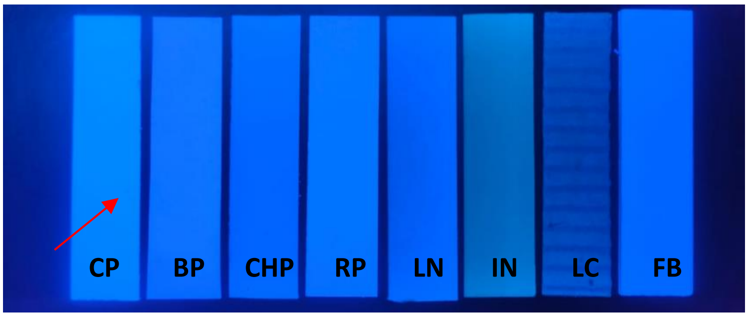

Fig. 9. UV examination for the detection of optical brighteners (OBs). The arrow points to the sample containing optical brightening agents.

3.4. Flame test and polarizing filters test

Sample FPL was identified by the flame test as cellophane, a non-plastic film. Cellophane, a form of regenerated cellulose manufactured from wood pulp, burns cleanly and completely like other wood derivatives [82]. It melted leaving a whitish bead. Cellophane is not recommended for storing photographic materials [83]. On the other hand, sample SPL was identified as polyester since it does not burn quickly compared to other plastics [84]. It also produced an orange flame with black smoke and melted leaving a hard black bead [85, 86] **(Fig. 10)**. Since many plastics share this property, a second test was conducted. The polarization test revealed the presence of rainbow-colored interference patterns in the SPL sample, characteristic of polyester.

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[81] Mustalish, R. 2000. Optical brighteners: history and technology, *Studies in Conservation*, 45(Supplement-1), pp. 133-136. DOI: 10.1179/sic.2000.45.Supplement-1.133

[82] Brasier, J. 1986. Cellophane — The deceptively versatile non-plastic, *Materials & Design*, 7(2), pp. 65-67. DOI:10.1016/s0261-3069(86)80003-6

[83] New South Wales State Library. 2024. Caring for photographs.https://www.sl.nsw.gov.au/research-and-collections/building-our-collections/caring-collections/caring-photographs#:~:text=When%20choosing%20storage%20albums%20or%20boxes%2C%20use%20inert%2C,polypropylene%29.%20Do%20not%20use%20PVC%20plastics%20and%20cellophane. [accessed 13/11/2024].

[84] National Park Service. 1999. Identification of film-base photographic materials, *Conserve O Gram*, 14(9). https://www.nps.gov/museum/publications/conserveogram/14-02.pdf [accessed 25/12/2019].

[85] Shah, V. 2024. Plastics and elastomers identification chart.https://www.consultekusa.com/pdf/Tech%20Resources/New%20ID%20chart%20.pdf. [accessed 13/11/2024].

[86] Fabric Mart. 2013. Resource library: the burn tests.https://blog.fabricmartfabrics.com/2013/01/resource-library-burn tests.html#:~:text=Polyester%3A%20Produces%20an%20orange%20flame%20with%20black%20smoke.,and%20the%20bead%20is%20hard%2C%20polyester%20is%20present. [accessed 13/11/2024].

Fig. 10. Flame test for the identification of plastics. Sample SPL was identified as polyester, while sample FPL was identified as cellophane.

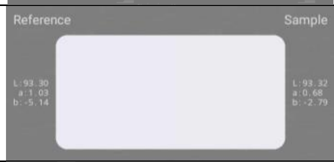
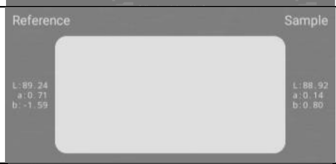
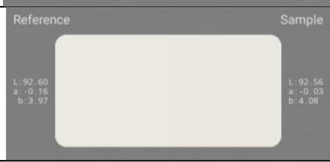
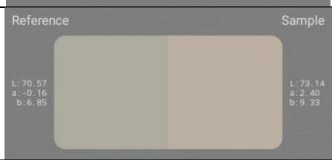
3.5. Colorimetric measurements

Artificial aging and prolonged contact with poor-quality materials have a great impact on the color of the enclosure material itself and the enclosed photographic material [87]. Change in color is related to the deterioration of materials. For example, upon aging, cellulose is oxidized forming compounds with double bond functional groups such as aldehydes, leading to discoloration. As previously clarified, lignin also causes discoloration of inferior paper-based materials [88].

The total color difference, Delta E* (ΔE*), is a reliable indicator of the difference between a sample and a reference [89]. Based on DIN EN ISO 53230 (super ceded by BS EN ISO 4628-1:2004), the evaluation of ΔE* is as follows: 0-1: not perceptible difference; 1-2: minimal color difference; 2-4: visible color difference; 4- 5: great color difference; and > 5: extreme color difference [90]. However, in the conservation field, ΔE* values ≤ 5 are acceptable [91]. L*, a*, b*, and ΔE* values for the storage materials are shown in **Table 2.** The color representations were obtained by using the Color Math 1.34 software.

[87] Lavédrine, B. 2003. A Guide to the Preventive Conservation of Photograph Collections, USA: Getty Publications.
[88] Małachowska, E., Pawcenis, D., Dańczak, J., Paczkowska, J., and Przybysz, K. 2021. Paper Ageing: The Effect of Paper Chemical Composition on Hydrolysis and Oxidation, *Polymers*, 13(7), 1029. DOI:10.3390/polym13071029
[89] Mokrzycki, W.S., Tatol, M. 2011. Colour difference δE - A survey, *Machine Graphics and Vision*, 20(4), pp. 383-411.
[90] Sahin, H. and Mantanis, G. 2011. Color changes in wood surfaces modified by a nanoparticulate based treatment, *Wood Research*, 56 (4), pp. 525- 532.
[91] Goffredo, G. & Munafò, P. 2015. Preservation of historical stone surfaces by TiO2 nanocoatings, *Coatings*, 5, pp. 222-231.

Table 2 L*, a*, b* and ΔE* values for tested storage materials for photographs.

Sample	Before aging			After aging			ΔE* Value	Color representation by Color Math 1.34 software
	L*	a*	b*	L*	a*	b*		
CP	94.31	2.91	-12.36	94.02	3.03	-11.84	0.47	
BP	93.19	2.22	-12.10	92.45	2.03	-11.22	0.75	
CHP	93.30	1.03	-5.14	93.32	0.68	-2.79	2.03	
RP	94.21	2.43	-12.76	93.22	2.25	-11.72	0.91	
LN	89.24	0.71	-1.59	88.92	0.14	0.80	2.47	
IN	92.60	-0.16	3.97	92.56	-0.03	4.08	0.21	
LC	70.57	1.42	6.85	73.14	2.40	9.33	4.29	
FB	92.91	1.10	-4.77	92.51	0.44	-1.89	2.64	
FPL	48.47	-0.91	1.20	50.63	-0.75	1.03	2.18	-
SPL	48.85	-1.04	0.46	49.68	-0.99	0.22	0.86	-

Based on the obtained results, five samples showed ΔE* values < 1 (i.e., CP, BP, RP, IN, and SPL). These values indicate an insignificant color difference. Four samples showed ΔE* values < 3 (i.e., CHP, LN, FB, and FPL). These indicate a detectable color difference by trained observers. The only sample showing a ΔE* value above 4 is sample LC **(Fig. 11)**.

Most samples showed a very slight decrease in the L* value indicating the darkening of the samples. The increase in the b* values indicates the yellowing of the samples. The color representation of sample LC via Color Math software visualizes this significant change in color **(Table 2)**.

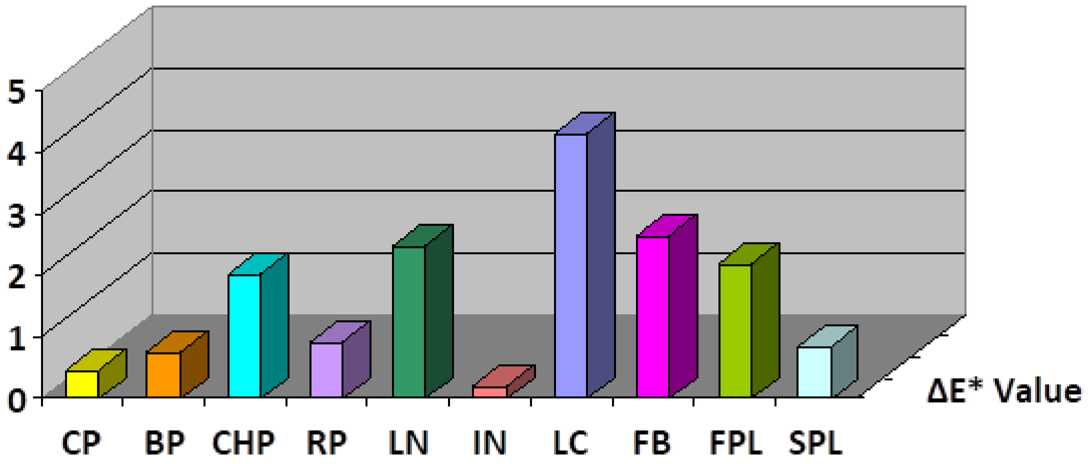


Fig. 11. ΔE* values for the aged storage materials compared to the unaged samples.

As for the photographic samples, for all image tones (i.e., highlights, D-min; midtones; and shadows, D-max), the total color difference (ΔE*) values were below 2 indicating that the change is insignificant in most cases such as sample (IN) which shows ΔE* values of 0.54, 0.58, and 0.45 for the D-min, midtones, and D-max areas, respectively; or minor in some cases such as (CHP) which shows ΔE* values of 2.63, 0.58, and 0.31 for the D-min, midtones, and D-max areas, respectively. Sample (LN) showed an observable color change in the midtones as indicated by the ΔE* value = 4.19.

L*, a*, b*, and ΔE* values for the photographic samples in contact with the selected storage materials are shown in **Table 3.** The color representations for the photographic sample in contact with sample LN were obtained by using the Color Math 1.34 software **(Fig. 12)**.

Table 3 L*, a*, b* and ΔE* values for photographic samples in contact with the selected storage materials for photographs.

	Before aging			After aging			ΔE* Value
	L*	**a***	**b***	**L***	**a***	**b***	
CP							
Highlights	90.57	1.17	-1.15	90.37	1.15	0.07	1.17
Midtones	75.95	0.18	0.96	75.05	0.18	1.59	0.88
Shadows	48.45	-0.57	1.71	48.86	-0.53	1.82	0.42

BP							
Highlights	89.42	0.66	-1.18	88.75	0.56	-0.77	1.08
Midtones	75.16	0.34	0.69	75.43	0.35	1.25	0.57
Shadows	48.25	-0.51	1.69	48.77	-0.49	1.75	0.52
CHP							
Highlights	88.55	0.58	-1.89	86.18	0.37	0.32	2.63
Midtones	77.57	0.40	0.23	77.32	0.37	0.79	0.58
Shadows	48.47	-0.57	1.65	48.75	-0.56	1.79	0.31
RP							
Highlights	87.71	0.64	-1.08	87.18	0.57	0.07	1.12
Midtones	81.49	1.00	0.17	81.36	1.00	0.73	0.55
Shadows	48.54	-0.55	1.74	48.91	-0.52	1.80	0.38
LN							
Highlights	90.63	0.77	-1.32	89.30	0.57	0.02	1.56
Midtones	72.49	0.43	0.50	78.24	0.34	0.79	4.19
Shadows	48.60	-0.59	1.72	48.87	-0.53	1.72	0.28
IN							
Highlights	88.62	1.09	-0.35	88.78	1.03	0.19	0.54
Midtones	82.52	0.58	0.00	82.24	0.50	0.54	0.58
Shadows	48.37	-0.54	1.68	48.81	-0.54	1.80	0.45
LC							
Highlights	83.76	0.61	-0.46	85.72	0.43	-0.21	1.34
Midtones	76.20	0.27	-0.10	74.96	0.19	0.68	1.19
Shadows	48.31	-0.61	1.70	48.86	-0.53	1.82	0.57
FB							
Highlights	87.03	0.42	-0.47	86.28	0.42	0.54	1.11
Midtones	77.36	0.33	-0.06	76.22	0.19	1.18	1.48
Shadows	48.45	-0.52	1.61	49.06	-0.48	1.69	0.64
FLP							
Highlights	88.09	0.94	-0.84	87.74	0.84	-0.26	0.62
Midtones	65.94	-0.01	1.23	67.81	-0.03	1.53	1.53
Shadows	49.22	-0.44	1.58	49.57	-0.41	1.71	0.73
SLP							
Highlights	93.90	1.44	-2.77	93.45	1.33	-2.24	0.50
Midtones	72.48	0.34	-0.02	71.81	0.29	0.39	0.65
Shadows	48.31	-0.61	1.74	48.70	-0.57	1.79	0.39

Fig. 12. ΔE* values and visual representation of the color change resulting from storage of photographic samples in sample (LN) post artificial aging. Highlights (left), midtones (center) and shadows (right).

3.6. Fourier Transform Infrared Spectroscopy (FT-IR)

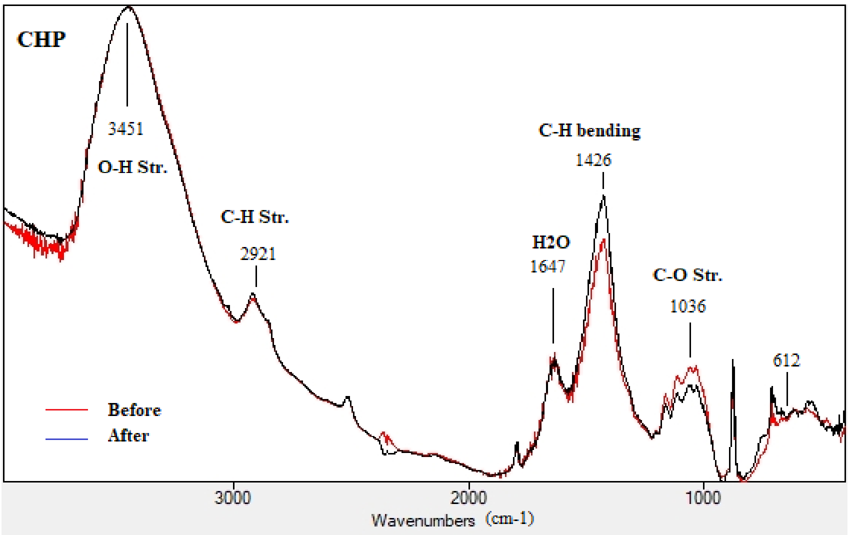


Fig. 13. FT-IR spectra of sample CHP before and after aging, in absorbance mode.

All paper and cardboard samples show a strong absorption in the region 1200 to 950 cm-1 which is the 'fingerprint' region of cellulose [92]. Samples gave rise to the following vibrations: the O-H stretching vibrations located at 3300 -3400 cm^{-1}, the C-H stretching vibrations located at 2800 -3000 cm^{-1}, the C-H bending vibrations at 1350 -1450 cm^{-1}, the C-O stretching vibrations at 1000 -1300 cm^{-1}, and CH rocking vibrations at < 900 cm^{-1}. The band observed at ~1640 cm^{-1} correspond to water molecules in the samples. Resultant FT-IR spectra show insignificant chemical changes for all samples **(Fig. 13)**, **(Fig. 14)**, **(Fig. 15)**.

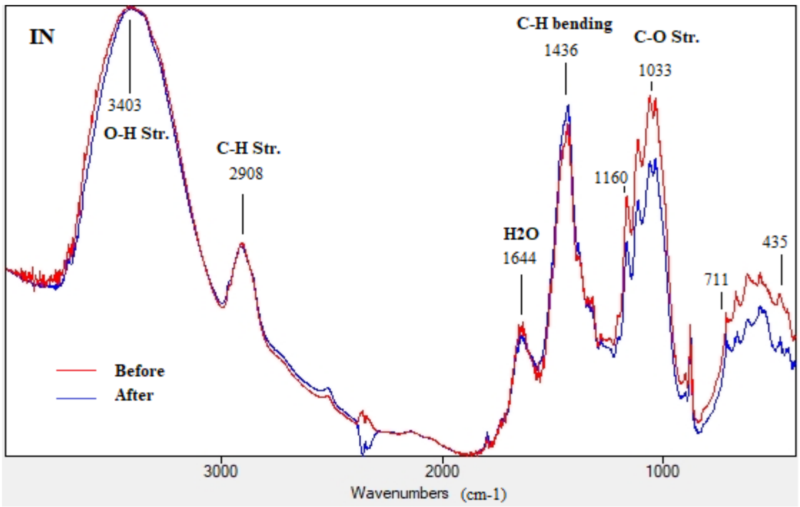


Fig. 14. FT-IR spectra of sample IN before and after aging, in absorbance mode.

[92] Batterham, I., Rai, R. 2008. A Comparison of Artificial Ageing with 27 Years of Natural Aging. *AICCM Book, Paper and Photographic Materials Symposium*.

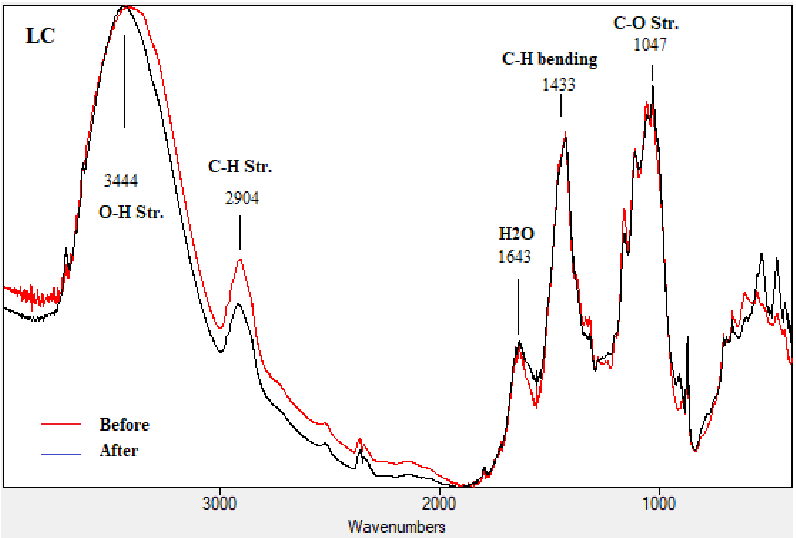


Fig. 15. FT-IR spectra of sample LC before and after aging, in absorbance mode.

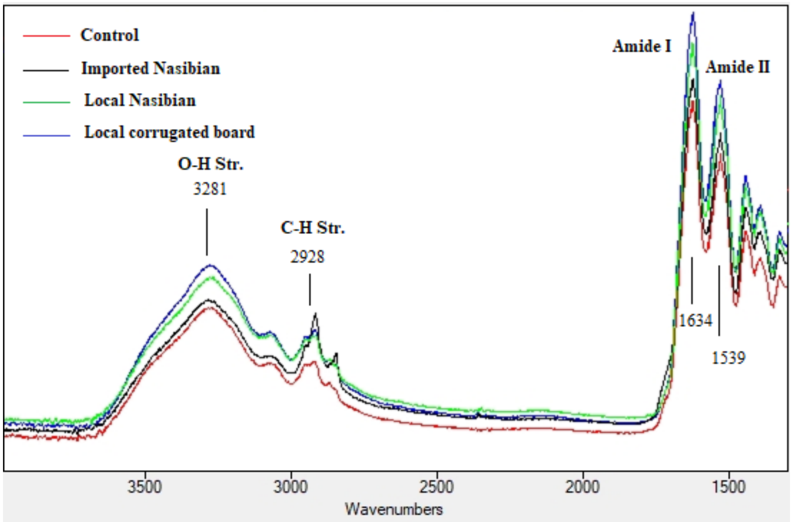


Fig. 16. FT-IR spectra of the artificially aged photographic samples in contact with imported Nasibian, local Nasibian, and local corrugated board, in absorbance mode.

As for the photographic samples in contact with the selected storage materials, they gave rise to the amide I and amide II bands which are characteristic of proteins (e.g., the photographic gelatin binder) at ~1634 cm^{-1} and 1539 cm^{-1}, respectively [93]. The amide I band is located within the 1600-1700 cm^{-1} region and is presided by the C=O stretching vibrations of the peptide linkages with very minor contributions from C-N groups [94]. The amide II within the 1500-1600 cm^{-1} region is a combination of the N-H

[93] Adochitei, A. and Drochioiu, G. 2011. Rapid characterization of peptide secondary structure by FT-IR spectroscopy, *Revue Roumaine de Chimie*, 56, pp. 783-791.
[94] Kong, J., and Yu, S. 2007. Fourier transform infrared spectroscopic analysis of protein secondary structures, *Acta Biochimica et Biophysica Sinica*, 39(8), pp. 549-559. https://doi.org/10.1111/j.1745-7270.200v7.00320.x

bending vibrations, the C-N stretching vibrations and the C-C stretching vibrations [95, 96]. The band at ~3281 cm^{-1} is attributed to the O-H stretching vibrations and the band at ~2928 cm^{-1} corresponds to the C-H stretching vibrations. Based on literature, the information required to predict the chemical changes which take place in gelatin is contained in the amide I and amide II bands [97]. Extremely minor changes have been observed for all photographic samples excluding those in contact with the local Nasibian and the local corrugated board. These two materials showed an increase in the intensity and width of the amide I band indicating the occurrence of hydrolysis and oxidation, respectively. The hydrolysis of gelatin can also be seen as an increase in the O-H stretching band [98]. The increase in the intensity of the amide I band is also related to the increase in the random coils at the expense of the ordered secondary structures (i.e., α-helices and β sheets) **(Fig. 16)**. For all photographic samples, the amide I bands were found within the range 1640 – 1620 cm^{-1}; these are assigned to β sheets [99], while the amide II bands were found at ~1540 cm-1; these are assigned to random coils [100].

The intensity of amide I and amide II bands were used to calculate the amide I/II intensity ratio (i.e., I_{AI}/I_{AII} ratio) for each photographic sample and the control sample [101]. Based on the obtained results, most photographic samples showed no to minor changes. However, the photographic samples in contact with the local Nasibian and the local corrugated board showed a decrease in the I_{AI}/I_{AII} ratio compared to the control sample which is related to a decrease in the protein level as shown in **Table 4**.

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[95] Adiguzel, Y., Haris, P. and Severcan, F. 2012. Screening of proteins in cells and tissues by vibrational spectroscopy, *Advances in Biomedical Spectroscopy*, 6, pp. 53-108. DOI: 10.3233/978-1-61499-059-8-53

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[97] Goldberg, M. and Chaffotte, A. 2005. Undistorted structural analysis of soluble proteins by attenuated total reflectance infrared spectroscopy, *Protein Science*, 14(11), pp. 2781-2792. DOI: 10.1110/ps.051687205

[98] Derrick, M. 1991. Evaluation of the state of degradation of Dead Sea scroll samples using FT-IR spectroscopy, *The Book and Paper Group Annual*, 10.

[99] Derrick, M. 1991. Evaluation of the state of degradation of Dead Sea scroll samples using FT-IR spectroscopy, *The Book and Paper Group Annual*, 10.

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[101] Al-Saidi, G., Rahman, M., Al-Alawi, A., and Guizani, N. 2012. Fourier transform infrared (FTIR) spectroscopic study of extracted gelatin from Shaari (Lithrinus microdon) skin: effects of extraction conditions, *International Food Research Journal*, 19(3), pp. 1167-1173.

Table 4 Comparison between the amide I/II intensity ratio of the photographic samples after artificial aging and that of the control sample.

	Wavenumber (cm^{-1})	Intensity	Assignment	(I_{AI}/I_{AII})
Control sample				
Amide I	1633	2.8	β sheets	1.75
Amide II	1536	1.6	Random coils	
Photographic sample in contact with the imported Nasibian				
Amide I	1632	2.8	β sheets	1.75
Amide II	1538	1.6	Random coils	
Photographic sample in contact with the local Nasibian				
Amide I	1633	2.8	β sheets	1.47
Amide II	1538	1.9	Random coils	
Photographic sample in contact with the local corrugated board				
Amide I	1632	3.3	β sheets	1.57
Amide II	1537	2.1	Random coils	

3.7. pH value measurement

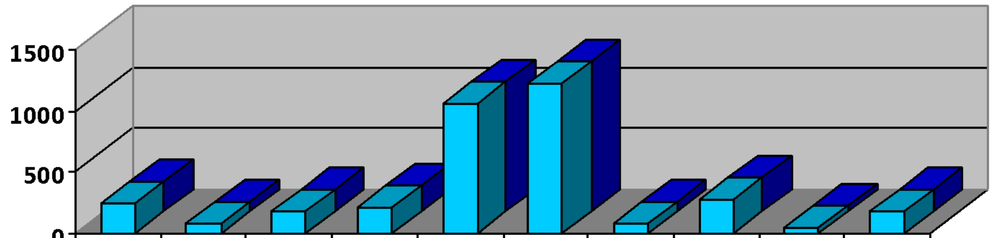
Table 5 shows pH value measurements for the selected storage materials before and after artificial aging. The obtained results revealed that all tested materials have pH values above 7, which is ideal for the storage of photographic collections. However, one must take into consideration that certain photographic materials such as the albumen prints, cyanotypes and color photographs are very sensitive to alkalinity, thus enclosure materials with pH values 7.5 and above are not recommended for their storage [102, 103].

Table 5 pH value measurements before and after aging.

Sample	Before aging	After aging
CP	7.77	7.91
BP	7.74	8.73
CHP	7.75	7.84
RP	8.24	8.18
LN	9.42	9.56
IN	7.66	7.40
LC	9.22	9.76
FB	8.25	8.29
FPL	7.82	7.46
SPL	7.31	7.10

[102] National Park Service. 1993. Storage Enclosures for Photographic Prints and Negatives, *Conserve O Gram*, 14(2). https://www.nps.gov/museum/publications/conserveogram/14-02.pdf [accessed 18/5/2010].
[103] Northeast Document Conservation Center. 2024. Storage Enclosures for Photographic Materials, Preservation Leaflet. https://www.nedcc.org/assets/media/documents/Preservation%20Leaflets/5_6_Enclosures.pdf [accessed 12/8/2024].

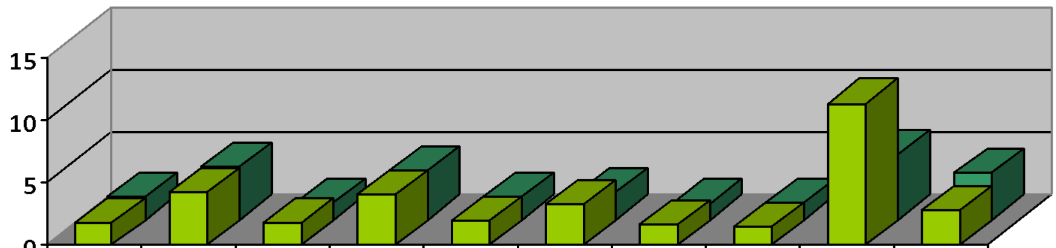
3.8. Mechanical properties



	CP	BP	CHP	RP	LN	IN	LC	FB	FPL	SPL
Before aging	244	89	178	220	1063	1228	90	283	45	180
After aging	242	88	173	219	1060	1221	83	281	43	179

Fig. 17. Change of tensile strength (Force in N) of aged storage samples compared to the unaged samples.

Tensile strength and elongation are more fundamental metrics compared to other conventional strength tests carried out on paper [104]. Samples showed minor decrease in tensile strength post artificial aging compared to the unaged samples **(Fig. 17)**. The obtained elongation values (%) also shows a minor change for all tested samples, excluding sample FPL which has become less flexible **(Fig. 18)**.



	CP	BP	CHP	RP	LN	IN	LC	FB	FPL	SPL
Before aging	1.72	4.13	1.68	3.94	1.83	3.23	1.61	1.42	11.31	2.73
After aging	1.89	4.25	1.36	3.9	1.84	2.12	1.29	1.33	5.22	3.77

Fig. 18. Changes of elongation (%) of aged storage samples compared to the unaged samples.

3.9. Thickness

Table 6 lists the thickness measurements in mm before and after aging. Results show an extremely slight decrease in thickness for all tested samples. To be more precise, they are not considered a significant change, scientifically speaking.

[104] Hanus, J. 1994. Changes in Brittle Paper During Conservation Treatment, *Restaurator*, 15(1), pp. 46-54.

Table 6 Thickness measurements before and after artificial aging.

Sample	Before aging (mm)	After aging (mm)
CP	0.272	0.270
BP	0.153	0.151
CHP	0.238	0.237
RP	0.296	0.293
LN	1.266	1.262
IN	1.033	1.032
LC	1.64	1.61
FB	3.085	3.084
FPL	0.028	0.026
SPL	0.153	0.152

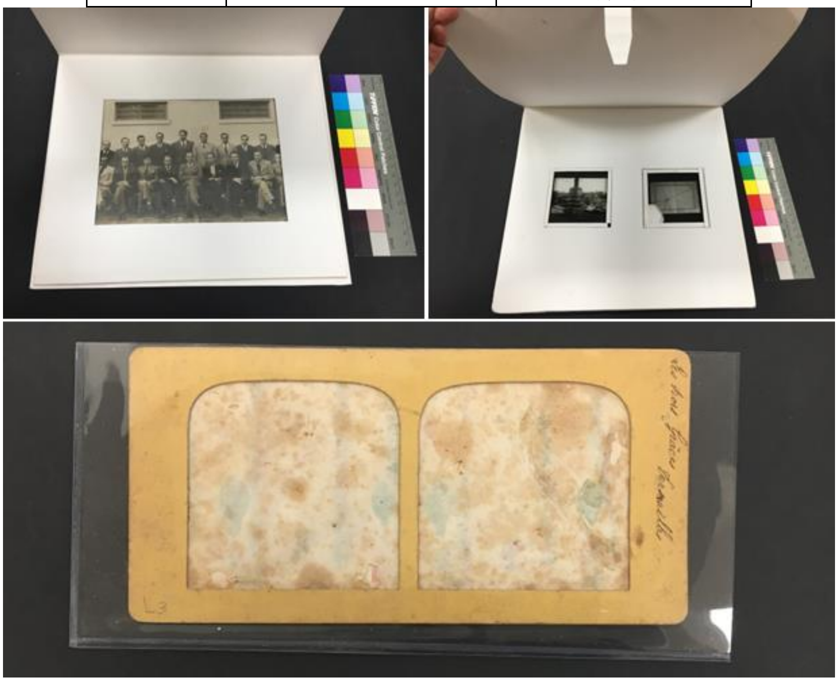


Fig. 19. Examples of enclosures made using locally available materials. Courtesy of Ali, M, Abdallah, M. and Henin, E.

4. Conclusion

High-quality materials that meet the known international standards for housing photographic materials are abundantly available through foreign suppliers; however, they are quite expensive. Due to the worldwide economic situation, importing is not an option, particularly as the Egyptian pound weakens against the US currency and the Euro. An alternative solution is to search in the local market for materials that may be appropriate for use in storing photographic collection and are consistently available. Four types of paper (i.e., Canson, Bristol, Cochet, and Rigoletto), four types of cardboard (i.e., local Nasibian, imported Nasibian, local corrugated board, and white foam board) and two types of plastics (i.e., flexible and stiff) were selected for this study. This study was carried out on silver gelatin prints since it is by far the most common photographic process for producing black and white positives. Scientific assessment was carried out on the selected materials and photographic samples in contact with these materials after artificial aging at a temperature of 80°C and 65% RH for a period of 2 days which is equivalent to natural aging for 10 years based on the ISO 5630-3:1996 standard. The following investigation and analysis techniques were used: visual inspection, microscopic inspection by digital microscope, ultraviolet light examination, flame test, polarization test, colorimetric measurements, Fourier transform infrared spectroscopy, pH value measurements, mechanical properties, and thickness measurements.

Visual and microscopic inspection showed no significant change in the appearance of the sample and a no to very slight change in color was observed in the photographic sample. Ultraviolet imaging was used to detect the presence of optical brightening agents (OBs). Results revealed the presence of OBS only in Cochet paper sample (CHP). The flame and polarization tests identified the stiff plastic (SPL) as polyester. Polyester produces an orange flame with black smoke and melts to leave a hard black bead. It also produces rainbow colors when viewed between two crossed polarizing filters. On the other hand, the flexible thought to be plastic sample (FPL) was identified as cellophane, a non-plastic film. Cellophane burns cleanly leaving a whitish bead. Colorimetric measurements showed insignificant changes as indicated by the measured ΔE^* values which were below 3. The only observable change was in the case of the local corrugated board with a ΔE^* above 4. The photographic samples showed no to minimal change in color excluding the sample in contact with the local Nasibian sample (LN). However, it is not a serious issue since the obtained ΔE^* value is below the acceptable limit in the conservation field. In terms of chemical changes, the obtained FT-IR spectra showed insignificant changes in the functional groups for all tested samples. Similar results were obtained for the photographic samples excluding the samples in contact with the local Nasibian and the local corrugated board which showed minor hydrolysis and oxidation of the gelatin binder. The measured pH values for all samples were above 7, in certain samples it exceeded the value of 9 (i.e., the local Nasibian and corrugated board). Samples showed insignificant change in the mechanical properties (i.e., tensile strength and elongation) as well as in their thickness.

Based on these results, the following materials should not be used for storing photographic materials: Cochet paper since it contains optical brighteners; cellophane since it does not meet the international standards for housing photographs; Bristol paper, Rigoletto paper, the local corrugated board, the local Nasibian, and the white foam board since they have pH values above 8 which is not appropriate for certain types of photographs that are highly sensitive to alkalinity such as albumen prints, cyanotypes and color photographs. However, they are proper for storage of silver gelatin prints. Results showed that the following locally available materials can be used in making safe enclosures for housing photographic materials: Canson paper, imported Nasibian cardboard and polyester **(Fig. 19)**.

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