Conservation and Restoration Program, Master's, Photography Specialization
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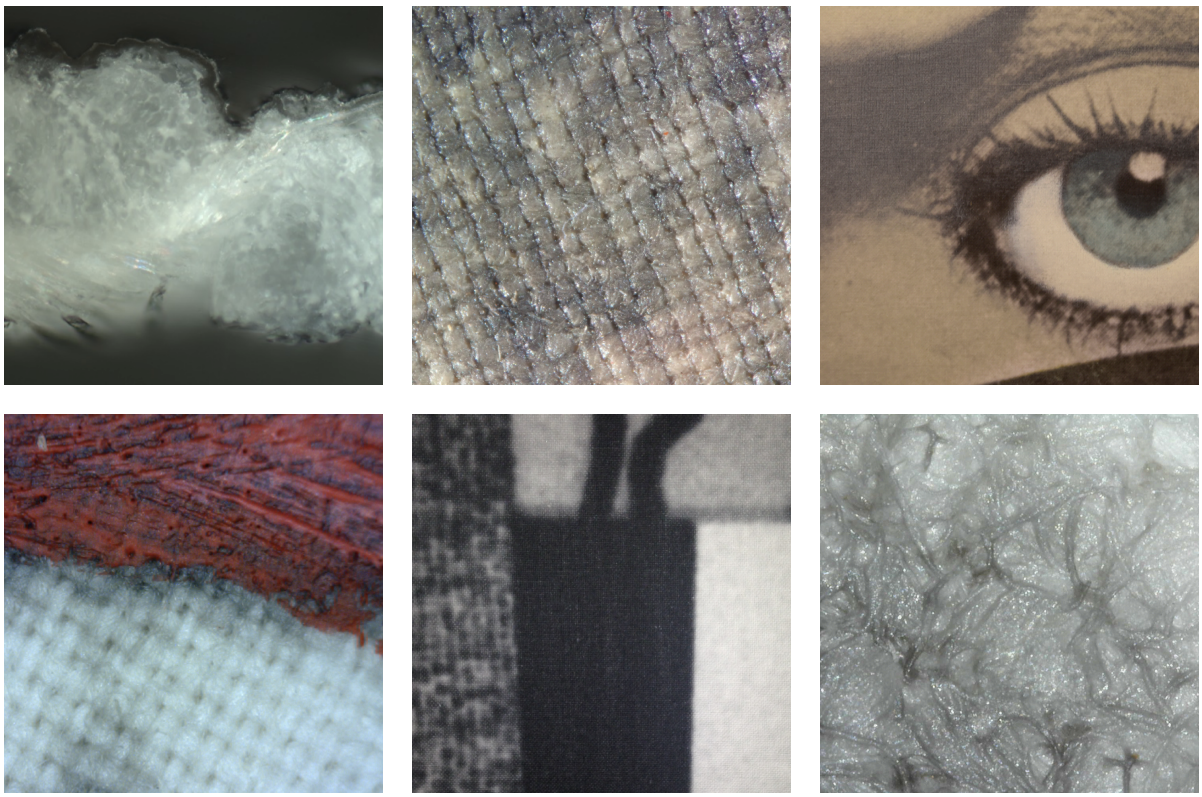
Master's Thesis

Shedding light on photo linen:
Defining an atypical silver gelatin developing-out material



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Cover images (clockwise from the top left):
Sample A-30960 (detail). Axioplan 2, bright field, 200x magnification.
Raetz, “Tonbandknauel”, Stedelijk Museum Amsterdam, 1970. Seizz Zoom.V16, 80x magnification.
Groenendijk, “Bescherm Engel”, RCE, 1978 (detail).
Kalksma, No Title, Museum de Lakenhal, 1987-1988. Dinolite AM4115TL-FVW, 200x magnification.
Kalksma, No Title, Museum de Lakenhal, 1987-1988 (detail).
Groenendijk, “3 Bakkers”, RCE, 1975-1976. Dinolite AM4115TL-FVW, 50x magnification.

CONTENTS

APPENDICES

WORDS OF THANKS

This thesis was written as final assignment for the Master's Conservation and Restoration of Cultural Heritage, photography specialisation, at the University of Amsterdam. The idea for a material characterization of photo linen was developed in consultation with my lecturer, and coordinator of this thesis, Clara von Waldthausen. She introduced me to this little-known material with a charming aesthetic. I am very thankful to the enthusiast guidance Clara provided during this research process.

The relevance of the research was confirmed by the many positive responses from collection managers and conservators throughout the project. Many of them provided their cooperation. I would like to give special thanks to Sandra Weerdenburg, Monica Marchesi and Tessa Rietveld of the Stedelijk Museum Amsterdam for their cooperation and time invested in this research. I am also very grateful for the input of Martin Jürgens from the Rijksmuseum Amsterdam. Hereby I also thank all collection managers and conservators who so kindly provided me their time and trust at Museum Boijmans van Beuningen, Museum de Lakenhal, Museum Helmond, Rabo Real Estate Group, the Cultural Heritage Agency of the Netherlands (RCE) and Van Abbemuseum.

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ABSTRACT

Shedding light on photo linen: Defining an atypical silver gelatin material
Master's Thesis

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University of Amsterdam, June 2017

The thesis *Shedding light on photo linen: Defining an atypical silver gelatin material* provides a characterisation of photo linen. Photo linen's limited popularity is reflected in the little knowledge about this silver gelatin material with a textile substrate. This diagnostic research focuses on ways to identify photo linen as a first step. The objective of this research is to create a basic understanding of photo linen's material qualities in order to aid in the identification of the material. The research is build-up from three components: a literature review, a technical survey of twenty-nine works on photo linen in seven Dutch collections and materials analysis of four photo linen samples provided by the Stedelijk Museum Amsterdam and photograph conservator Martin Jürgens.

It was found that the history of photo linen goes back to the last quarter of the 1800's when 'linographies' were made on linen. Improvements were made over the following decades that resulted in 'early modern' (1930's-1960's) and 'modern' (1960's-1990's) photo linen. In this research the focus is on modern photo linen. This modern photo linen commonly has a plain-woven, cotton substrate. For this substrate at least two types of pre-treatments existed: a coating with a pigmented layer or a coating made by transparent impregnation. Common factor is that all modern photo linen products are coated with a regular silver halide emulsion that was also used on developing-out papers (DOP's), resulting in monochrome, continuous tone images.

Since the image layer is comparable, it is not surprising that the chemical aging qualities of the image layer of photo linen are comparable to chemical deterioration forms encountered on DOP's: silver image oxidation and aging of the gelatin under the influence of pollutants, high heat or radiation and moisture are common. The substrates were found to be chemically relatively stable. Physical deterioration of photo linen has a more individual character and often results from a combination of the preferred format for photo linen mounted onto a stretcher frame, the large dimensions of the works and the heavily textured surface.

SAMENVATTING

Fotolinnen in de schijnwerpers: Beschrijving van een atypisch zilver gelatine materiaal
Master scriptie

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De scriptie *Fotolinnen in de schijnwerpers: Beschrijving van een atypisch zilver gelatine materiaal* geeft een karakteristering van fotolinnen. De beperkte populariteit van fotolinnen wordt gereflecteerd in de beperkte kennis over eigenschappen van dit materiaal. Dit diagnostische onderzoek focust op de identificatie van fotolinnen. Het doel van dit onderzoek is een elementair begrip van fotolinnen te verkrijgen ten behoeve van diens identificatie. Het onderzoek is opgebouwd uit: een literatuuronderzoek, een visueel onderzoek van negentwintig werken op fotolinnen in zeven Nederlandse collecties en materiaal analyses van vier fotolinnen monsters beschikbaar gesteld door het Stedelijk Museum Amsterdam en fotorestaurator Martin Jürgens.

De geschiedenis van fotolinnen gaat terug tot het laatste kwart van de negentiende eeuw toen ‘linografieën’ gemaakt werden op linnen. Verbeteringen in dit product in de daaropvolgende decennia resulteerden in ‘vroeg modern’ (jaren ’30-’60) and ‘modern’ (jaren ’60-’90) fotolinnen. In dit onderzoek ligt de focus op modern fotolinnen. Dit type bestaat gewoonlijk uit een plat geweven katoenen drager. Deze drager kon op ten minste twee manieren worden voorbehandeld: met een gepigmenteerde coating of met een doorschijnende impregnering. Gemene deler voor alle moderne fotolinnen producten is dat ze zijn gecoat met reguliere zilver gelatine emulsies die ook gebruikt werden op zilvergelatine ontwikkelpapieren.

Omdat de beeldlagen vergelijkbaar zijn, is het niet verrassend dat de vormen van chemisch verval van de beeldlaag van fotolinnen en zilvergelatineontwikkelpapieren vergelijkbaar zijn: zilveroxidatie en veroudering van de gelatine onder invloed van schadelijke gassen, hoge energie in de vorm van temperatuur of straling en vocht komen geregeld voor. De drager van fotolinnen is chemisch relatief stabiel. Fysiek verval van fotolinnen heeft een meer individueel karakter en komt vaak voort uit een combinatie van het feit dat fotolinnen in veel gevallen is opgespannen op een spanraam, het formaat van werken op fotolinnen vaak groot is en het materiaal een grove oppervlaktestructuur heeft.

1. INTRODUCTION

1.1 Introduction to the research topic

Since its introduction in the 1890's, silver gelatin developing-out prints (DOP's) became the most important photographic process of the twentieth century.[1] DOP papers are still produced today.[2] The process is commonly known as (silver gelatine) black-and-white photography. As has been the case with all photographic processes, photographers and manufacturers experimented with different ways of using the DOP process to reach certain material characteristics or a specific aesthetic. This was for example done by applying the light-sensitive gelatin emulsion onto substrates other than the commonly used baryta-coated papers. One of the substrates that can be used, besides ceramics, glass or film, is textile.[3]

The focus of this research is on one specific type of such a textile substrate: photo linen. Photo linen was commercially produced and pre-coated with a silver gelatine emulsion to create black-and-white photographic images on textile.[4] It was first marketed in 1963 for theatre and advertising purposes.[5] Later, other companies produced comparable products. In the late 1990's, when digital photography was introduced, the production of analogue photo linen seems to have diminished. At the time of writing analogue photo linen is no longer available. However, several prepared textile substrates are available for inkjet printing.[6]

Photo linen has never been a common photographic material. Its limited popularity is reflected in the limited amount of works on photo linen in collections throughout the Netherlands and the limited understanding of the material characteristics of photo linen by collection managers and conservators. What is known about the material composition is that photo linen consists of at least two layers: the textile substrate and a gelatine silver halide emulsion.[7] The light-sensitive silver halides are exposed and processed like regular DOP's to create a monochrome photographic image on textile.[8] However, basic information about the composition and behaviour of photo linen, such as the type of textile used for the substrate, the presence of additional layers on this substrate and the characteristics due to aging and use of the material has not been published in the conservation field, nor are there publications in the wider academic field.

1.2 Research objective and relevance

Although their number is limited, works on photo linen did find their way into private and institutional collections over the last decades and collection managers and conservators are faced with their care. The lack of knowledge about how photo linen is made, how it was used and how it deteriorates hinders its identification and complicates setting preservation

[1] Stulik, 2013 [B]: 27.
[2] Ibidem.
[3] Lavédrine, 2003: 92.
[4] ORWO, 1973 [A]: 1.
[5] Guttierez, 2014: 148, Desfor, 1963 [B]: 12.
[6] See for example: Arista-II. *Technical datasheet Arista-II Premium Inkjet Canvas*. Arista-II, 2014 and Canson. *Technical datasheet Infinity® PhotoArt Pro Canvas 395gsm – Lustre or Matte*. Canson, 2017.
[7] Gayer,1995: 193, Farkas, 1980: 131.
[8] Gayer, 1995: 193.

guidelines. When thinking about conservation strategies concerning photo linen it brings about uncertainty about the material's behaviour. Without understanding the composition and aging of photo linen, reactions to mechanical treatments such as dry cleaning, aqueous or solvent-based treatments like surface cleaning, tape removal, flattening or mounting or the use of heat for flattening or adhesive reduction cannot be predicted accurately.

This diagnostic research focuses on ways to identify photo linen as a first step in their preventive and active conservation. Identification is necessary to identify these works in collections and to devise suitable preventive and active conservation measures for photo linen works. The objective of this research is to sketch the history, composition and fabrication, use and degradation of photo linen. With the resulting information a basic understanding of its material qualities will be established. The main conclusions following from the interpretation of the results can be used as identification guidelines for photo linen and as a basis for its preventive conservation.

The main research question is: *What are the material characteristics and aging qualities of photo linen?* In order answer this question the following sub questions need be answered:

- What is the material composition of photo linen and are there different varieties?
- How was photo linen produced?
- How was photo linen used?
- In what ways does photo linen degrade?

The basic comprehension of the material characteristics and aging qualities will be of relevance to the field of photograph conservation by:

1. Providing conservators and collection managers with a technical history of photo linen to improve their understanding and awareness of this material.
2. Providing conservators and collection managers with guidelines to correctly identify and preserve photo linen works.
3. Function as a basis for further research into the use, behaviour and conservation guidelines of photo linen works.

1.3 Current scientific knowledge

The limitedly available literature provides a valuable starting point for this research. John Gayer (1995) discusses an emulsion-coated canvas designed for theatre and advertising purposes by the company Argenta.[9] This "Photoleinen" was a cotton fabric coated with a gelatin layer pigmented with barium sulphate and titanium oxide. A photographic emulsion of medium gradation, like the one used in the manufacture of photo papers, was applied on top. Sheets of photo linen were impregnated with a bromide emulsion and rolls of photo linen with a chlorobromide emulsion. Gayer states about the emulsion: *"It was also unwashed, that is, all superfluous salts were left in the emulsion."*[10]

Jennifer Jae Guttierez (2014) discusses artist Robert Heinecken's use of photo linen. He used Argenta photo linen and just as Gayer she states that this material can be processed and handled just as other silver gelatin enlarging papers. Guttierez' source for

[9] Gayer, 1995: 193.

[10] Gayer, 1995: 193. In this quote Gayer refers to a step in the process of the preparation of a silver halide emulsion called 'washing'. After emulsification and ripening of the emulsion soluble by-products of emulsion manufacture are present in the gelatin. These are dissolved chemicals that in modern times are usually removed since they may reduce the shelf-life or performance of the emulsion. Several processes were developed to wash the emulsion. For more information, see Hodgson, 2007: 641-649.

this product information was a newspaper article from 1963. Heinecken stapled the photo linen to wooden stretchers and enhanced the image with different media like acrylic paint and coloured chalk.[11]

All other sources name photo linen in the light of alternative photographic processes that became popular in the 1960's. These processes strayed from mass-production, were often handcrafted and looking back on early photographic processes and crafts.[12] In this context photo linen is named as pre-made alternative for hand-coating textile with a light-sensitive emulsion. In *Photographic Possibilities: The Expressive Use of Ideas, Materials and Processes* (2001) Hirsch introduces photo linen from Luminos Photo Linen. This is a manufactured cloth treated with a photographic emulsion that tends to have more contrast than emulsions that can be applied directly to fabric by hand.[13]

In 1980 in the journal *Leonardo* Farkas and Raleigh also describe photo linen as a *"White fabric coated with a black-and-white photographic emulsion (produced by Rockland Colloid, Piedmont, NY, U.S.A.). It is available in sheets and is used in the same manner as ordinary photographic paper."*[14] In addition, Jones mentioned the availability of a pre-coated linen material produced by Neobrom and the recent introduction of a comparable material by Hans O. Mahn in 1995.[15]

A more recent source on the availability of photo linen is Blacklow. In *New Dimensions in Photo Processes: A Step-by-step Manual for Alternative Techniques* (2007) she mentions the contemporary availability of Luminos Photo linen (roll and sheets), Cachet Structura Lux Photo Linen (distributed by Hans O. Mahn and Calumet) and Fotospeed's photo linen. She also mentions photo linen is sturdy, but pliable and to be treated with regular darkroom chemicals.[16]

1.4 Research layout

The research described in this thesis is divided into three parts. The first part is a literature review and is performed to obtain insight into the history, composition and production and use of photo linen. The second research component is a technical survey of a selection of photo linen works. The survey is carried out to identify identification characteristics of photo linen, observe its forms of deterioration forms and gain insight into the different ways photo linen has been used. In the third research component four photo linen samples are investigated to gain understanding of the composition of the samples.

In chapter 2 a technical history of photo linen will be presented based on the results of the literature review. In chapter 3 the research methods of the technical survey and sample examination will be defined. In chapter 4, the results of the research will be presented. In chapter 5 the results will be discussed and the main conclusions are discussed in chapter six.

[11] Guttierez, 2014: 148.
[12] Lavédrine, 2009: 163.
[13] Hirsch, 2001: 102.
[14] Farkas and Raleigh, 1980: 131.
[15] Jones, 1995: 63.
[16] Blacklow, 2007: 246. Critical note on this last source it that the first edition of this book dates from 2000 and it needs to be questioned whether it was checked whether all these photo linens were still available in 2007. Attempts to contact the author were unsuccessful at the time of writing.

2. LITERATURE REVIEW: A TECHNICAL HISTORY OF PHOTO LINEN

2.1 Introduction

A literature review was conducted with a focus on consulting primary technical sources, such as patents and product brochures concerning the material composition and use of photo linen. The review was complemented with supporting information on the history, availability, composition and use of photo linen. A wide variety of sources were used, ranging from photographic handbooks to personal communication with (former employees of) photo labs.

2.2 Early photo linen products (last quarter 1800's-1930's)

Photographs on textile substrates have a long history. The first, introduced in 1853, were the so-called pannotypes that consisted of a collodion photograph on a waxed textile fabric.[17] The use of textile was an alternative to the less dimensionally stable supports, like glass and paper.[18] In 1877 the first manufacturer of 'linographies', a version of Calotypes on linen, opened in Vienna.[19] The first commercially produced photo linen was available in 1892 and in 1903 at least five manufacturers made photo linen.[20]

These products were mainly used to make photographic enlarged portraits to be over-painted with oil paint.[21] Eder, who wrote a comprehensive handbook for photography, mentions that the substrate of these early photo linens was always linen. The linen was coated with starch. Thereon a silver chloride or silver bromo-iodide solution was coated without a binder [Diagram 1]. These silver halides were converted into metallic silver with pyrogallic or gallic acid development.[22] The thin coating left the textile structure open and provided the photograph with a desired painting-like aesthetic.[23] The material resulted in poor quality images due to the low light-sensitivity of the material, the lack of a separation layer between the substrate and light-sensitive layer and the heavily textured surface of the fabric.[24]

In the following decades fabrics started to be treated in such a manner that they could be coated with a silver gelatin emulsion that was commonly used on photographic papers [Diagram 2].[25] This was initially done in different methods. The first method was to let paper strips run along the back of the fabric during coating. The paper was intended to prevent the light-sensitive material from reaching the back of the material to create a flawless white back and minimize the loss of expensive silver halides. The second method was to adhere paper with a water-based adhesive to the verso of the fabric to prevent the emulsion from reaching the back during production and create extra dimensional

[17] Lavédrine, 2009: 92.
[18] Ibidem.
[19] Eder, 1972: 325, 791.
[20] Eder, 1903: 40.
[21] Ibid.: 38-40.
[22] Eder, 1972: 325.
[23] Eder, 1903: 40.
[24] Deutsche Demokratische Republik, 1973: 2.
[25] Ibidem.

stability.[26] The resulting products created much better contrast images than the initial 'linographies' and were in use until at least the 1930's.[27]

2.3 Early-modern (1930's-1960's) and modern (1960's-1990's) photo linen

In the following period manufacturers started to look for ways to improve these early photo linens. The aim was not only to improve the aesthetic qualities and workability of the material, but also to reduce the amount of money and time invested in their production by enabling processing with regular paper coating methods.[28] The product developments took place mainly along the line of the type of pre-treatment for the textile substrate. As will become clear, based on the dating and use of the different photo linen products a division between 'early modern' and 'modern' photo linen can be made.

Substrates

The term 'linen' refers to a fabric woven from the bast fibres of the flax plant.[29] Since Eder mentions it explicitly in his "*History of Photography*" it is likely that the earliest photo linens indeed used linen as a substrate. As mentioned before these materials were used as a painting substrate, and linen was the most common material for painters' canvases at the time.[30] However 'linen' is also a term used to describe a plain weave. This weave consists of alternating one warp and one weft thread. This second type of weave was exclusively encountered in the photo linen works surveyed during this research.[31]

Based on product information, a cotton-based 'lawn fabric' was commonly used as a substrate for photo linen after the 1960's.[32] Lawn is a plain weave linen or cotton fabric that is usually starched or sized.[33] When cotton was first used for the manufacture of photo linen is not clear, but it is known that cotton fabrics were used in combination with light-sensitive coatings as early as 1930.[34] In patents from the 1950's to the 1990's relating to textile substrates for the use with light-sensitive layers a wide variety of fabrics are proposed. Whereas in some cases only linen or cotton sufficed, others opted for the use of amongst others nylon, fabric of artificial cellulose fibres (polynostic fibres) or even non-woven fabrics.[35] In specific photo linen patents it was found that all 'common' fabrics would suffice as substrates for photo linen.[36]

Pre-treatment of the substrate

As described above, in the earliest products silver gelatin emulsions were directly applied to fabric substrates. In this case the emulsion was largely soaked up by the substrate and

[26] Kaiserling, 1903: 164.
[27] Deutsche Demokratische Republik, 1966: 2.
[28] Deutsche Demokratische Republik, 1973: 1.
[29] 'Linen' Cameo.
[30] 'Canvas' Cameo.
[31] 'Plain weave' Cameo.
[32] ORWO, Argenta newspaper, Fachbereich, Fotospeed
[33] 'Lawn fabric' Cameo.
[34] European Patent Office, 1930: 6.
[35] European Patent Office, 1930: 6; 1959 [A]: 2; 1959 [B]: 3; 1970: 1. Deutsche Demokratische Republik, 1966: 1.
[36] Deutsche Demokratische Republik, 1973: 1. Deutsche Demokratische Republik, 1966: 1.

could seep through it, resulting in blotchiness from the silver visible on the back of the support, as well as spillage of the emulsion during coating.[37]

After the 1930's the preparation of substrates changed extensively. Substrates started to be pre-treated with two layers: a hydrophobic impregnation with thereon a hydrophilic coating [Diagram 3].[38] The hydrophobic impregnation resulted in a substrate that had dimensional stability during processing and water-resistance. Materials described to for this layer were (mixtures of) oils, waxes and natural or synthetic resins.[39] The hydrophilic coating, consisting of high-molecular weight materials such as Polyvinyl alcohol (PVOH) or nitrocellulose, functioned as a subbing layer to assure good adhesion between the substrate and the photographic emulsion.[40] Both layers were commonly applied by bathing the fabric in tanks.[41] The resulting product of such a two-step pre-treatment often resulted in a very stiff substrate with a completely covered the weave structure.[42] In this period, until the 1960's no indications were found for the availability of photo linen for non-professional use. Substrates with this two-layer pre-treatment could be coated with silver gelatin or Diazotype emulsions and were used by designers to trace patterns and by architects to copy blueprints.[43] Materials from this period are referred to in this research as 'early modern'.

In the 1960's photographic materials manufacturers first marketed photo linen for both professional and non-professional use. Photo linen produced from this period onward is in this research referred to as 'modern'. For these materials the visibility of the weave structure, its flexibility, its water-resistance, the possibility to print large-format images and to use them in combination with backlighting were the most important characteristics. In 1963 Argenta introduced their 'Photoleinen'. This product has a cotton substrate that was pre-coated with a pigmented layer that consisted of hardened gelatin with barium sulphate and titanium oxide to reduce its absorbency [Diagram 4].[44] The application procedure of this coating, two-sided or one-sided application, could not be traced during this research. In any case this baryta-like layer provided an even ground on the recto for the emulsion and resulted in bright white highlights in the image.[45]

A few years later, in 1996, Vephota (from the 1970's ORWO) introduced photo linen with another pre-treatment: photo linen with a transparent one-layer impregnation [Diagram 5].[46] This single layer was composed of both hydrophobic and hydrophilic components. The hydrophobic component was a paraffin or paraffin-aluminium oxide mixture. This was mixed with a suspension of a hydrophilic, high-molecular weight material. The composition of this mixture ensures the water-resistance of the fabric, but also provided enough wettability for the photographic emulsion to adhere well.[47] The impregnation was applied by bathing the fabric in the mixture.[48] The production of photo linens using this process was faster and cheaper because the coating step was omitted and

[37] Deutsche Demokratische Republik, 1973: 1.
[38] European Patent Office, 1930: 1. Deutsche Demokratische Republik, 1973: 1.
[39] Deutsche Demokratische Republik, 1996: 1.
[40] Deutsche Demokratische Republik, 1973: 1.
[41] Ibid.: 2.
[42] Ibid.: 1.
[43] Deutsche Demokratische Republik, 1973: 3. Diazotype emulsions result in warm-white and blue/purple images. This process is commonly used to create the blue images on blueprints.
[44] Gayer, 1994: 1.
[45] Deutsche Demokratische Republik, 1973: 1.
[46] Personal communication with Uwe Holz, 18-05-2017.
[47] Deutsche Demokratische Republik: 1966: 2.
[48] Ibidem.

the impregnation was applied as a very diluted, watery emulsion. After bathing the substrate was squeegeed or dried in a heat calendar (100°C) or hot air drying tunnel.[49]

How the physical properties of these two types of pre-treatment of modern photo linens compare does not become clear based on the found results. Based on the findings however, it seems very likely that both types of photo linen existed next to each other for at least the 1960's, 70's and 80's.[50]

Emulsion coating

After fabric preparation the light-sensitive coating, which was either a silver halide gelatin emulsion (or, in theory, a Diazotype emulsion used to create cloths for architectural drawings reproduction), could be applied in the dark.[51] Due to the prior pre-treatment of the fabric the light sensitive emulsion could be applied using common methods used for coating photographic papers.[52] This means the width of the photo linen was limited by the size of the coating apparatus. The maximum width encountered in product information of photo linen is 127 cm.[53] The most common application method for emulsions is the slot-die method. Here the substrate passes under a coating head that flows the emulsion onto the width of the substrate in a steady stream covering it completely as it moves forward.[54] The coating is then cooled to set and dried in a drying tunnel.[55]

Although patent information is not conclusive about the type of silver gelatin emulsion that was used, from contemporary product information between the 1960's and the 1990's can be concluded that most likely bromide or chloro-bromide emulsions were used. Those were typical emulsions used for photographic paper coating.[56] Product information also clarifies that the gelatin emulsions were of medium gradation.[57] Interesting is that Argenta did not wash the emulsion for their photo linen, leaving the soluble by-products from emulsion manufacture in the emulsion.[58] These dissolved chemicals can shorten the shelf life and performance of the unprocessed product, but were washed out during processing.[59] Commonly in this period silver gelatin emulsions contained hardening agents to increase their physical stability.[60]

Processing took place in regular DOP chemicals.[61] Just like DOP's the photographic images on photo linen could be toned and finishing techniques such as retouching, coatings or hand colouring could be applied to the image. [62] Like photographic papers photo linen could be flatted in a heat press (or be ironed for bigger pieces) and due to the textile carrier, was very suited to be mounted onto a stretcher frame. This mounting onto a stretcher frame was preferably carried out wet, so the substrate would tighten around the frame upon drying.[63]

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[49] Deutsche Demokratische Republik: 1966: 2.
[50] Gayer, 1994: 1.
[51] Deutsche Demokratische Republik, 1973: 3.
[52] Ibidem.
[53] Desfor, 1963 [B]: 61
[54] Hodgson, 2007: 647.
[55] Ibidem.
[56] Hodgson, 2007: 641.
[57] Gayer, 1994: 2.
[58] Gayer, 1995: 193.
[59] Hodgson, 2007: 646.
[60] Gayer, 1994: 2. Sturmer, 1989: 92.
[61] ORWO, 1973 [A]: 13. ORWO, 1989: 55. Desfor, 1963 [A]: 12.
[62] ORWO, 1973 [B]: 3.
[63] ORWO, 1973 [A]: 15-16.

3. RESEARCH METHODS

3.1 Introduction

This chapter describes the procedures for the two practical research components. They will be ordered according to the increasing magnification needed to obtain information. The technical survey focussed on all information that could be gained of the material aspects of photo linen through visual examination and lower magnifications. Therefore the method of this research component will be described first. This will be followed by a detailed description of all steps taken in the different components of the materials analysis. In order of increasing magnification the procedures of the fibre-analysis, optical microscopy of the cross-sections and FTIR-ATR imaging will be described in this section.

3.2 Procedure for the technical survey

Selection of photo linen works for the survey
A technical survey was carried out of a selection of works on photo linen in various Dutch modern art collections to inventory their general condition and aging forms. The collections were contacted and selected on the basis of initial online collection database research and personal communication with professionals in the field. Large Dutch modern art museums as well as smaller corporate collections were contacted. As a result seven institutions which owned work on photo linen were willing to provide access to their objects for this research: Stedelijk Museum Amsterdam (SMA) (10), Museum Boijmans van Beuningen (BVB) (7), Museum de Lakenhal (1), Museum Helmond (1), Rabo Real Estate Group (1), the Cultural Heritage Agency of the Netherlands (RCE) (109, 10 selected) and Van Abbemuseum (VAM) (3).

Due to time constraints it was not possible to survey all 132 works on photo linen in these collections. To obtain the most meaningful results a broad selection was made that included differentiating artists and dates of production and different works from the same artist. Moreover, three objects that were wrongly identified as photo linen works were selected to understand the identification pitfalls for the collection staff when identifying these works.[64] The last factor that played a role in choosing the works was the availability and accessibility of the objects in the time that this research took place. As a result a selection of twenty-nine works on photo linen, one inkjet print on canvas, one collage including silver gelatin DOP's mounted onto a textile substrate and one chromogenic print on paper mounted onto a textile substrate were surveyed for this research.

Method of surveying
The works were assessed in order to find common ground in the visible deterioration forms that photo linen exhibits through time. An assessment form was developed. The use of a tailor-made form is the easiest way to effectively and systematically conduct a condition assessment and to get comparable results. This form was based on existing condition assessment forms, but aimed towards photographs on textile. The form was divided into

[64] The survey forms for these non-photo linen works will be included in this thesis. However, the results of these three surveys will not be described explicitly since they only functioned as aid in understanding on what characteristics identification of photo linen primarily fails.

several parts: deterioration of the image layer and deterioration of the substrate.[65] Whereas for photo linen the 'regular' categories used to qualify the image layer were implemented, as for example the different types of image silver oxidation, the textile substrate needed terminology other than used for photographs on paper. Here terms borrowed from textile and painting conservation literature to describe deterioration of natural fibres were chosen.[66]

Because there was no understanding of the different appearances photo linen could have and because there was not baseline for how it deteriorates, it was initially difficult to focus on deterioration aspects during examination. Acquaintance with the material characteristics had to be made. As a result, many loose notes were made that did not directly fit into the form. However, after the first assessments insight grew into the deterioration forms, but also into the general material characteristics of photo linen. The survey form was adjusted as needed based on the observed deterioration forms. During the survey it became apparent that information about the technical and material characteristics could also be retrieved from the object assessments, in addition to specific condition assessment. The form was adjusted accordingly with sections added for general material characteristics of the image layer and textile substrate, format of the object and the housing and storage conditions of the works.

Visual assessment was carried out using a head loupe and a bright daylight lamp using LED lighting. Microscopic examination could be carried out on location with the use of a Dinolite USB microscope, model AM4115TL-FVW, with normal light. This examination was chosen to provide information about the surface character and deterioration forms at different magnifications. The weave density was counted with the use of a thread counter, which is a mini-loupe with a scale-bar attached to it that needs to be placed directly on the fabric. This tool requires a rigid background behind the photo linen, such as the wooden stretcher frame to prevent mechanical damages. Extensive photograph documentation was made using a Nikon D750 with a 60mm lens throughout surveying. When available, documentation about the history of use and conservation of an object was consulted to support the observations made during the survey. During the assessment a technical survey form was filled for each object.

3.3 Procedure for materials analysis

Sample selection

The initiation of sample selection was preceded by reflection on the ethical considerations of removing original material to function as a sample. In general, non-invasive examination of objects is always preferable in the conservation field. However, for this research, the aim of which is to create a baseline for what photo linen is and how it can be identified, non-invasive examination cannot provide the needed information. The recto (front, image side) and verso (back) of the material can be examined and analysed with non-invasive techniques, but no information can be obtained about the layered structure of photo linen. It was therefore decided that limited invasive measures are justifiable. The sample-analysis will be able to add to the conservation field by furthering knowledge about photo linen and thereby could aid in the future preservation, interpretation and promotion

[65] These categories are loosely based on the categories as devised by Weaver, 2008: 10-15 and as used by C. von Waldthausen for the 'Controlelijst conditie/Fotografie'. Comparable divisions are commonly used in the photograph conservation field where objects are commonly discussed layer-wise.

[66] Sources used were Berger (1994), Eastrop and Timár-Balázsy (1998), Keyser (1984), Landi (1998) and Mecklenburg (1994).

of photo linen works. This argumentation is in line with the ICOM Code of Ethics for Museums.[67]

The first step in sample selection was to find sample material. The largest Dutch modern art museum, Stedelijk Museum Amsterdam (SMA), was approached to ask for their cooperation. Monica Marchesi and Tessa Rietveld, the museum's paper conservators responsible for care of the photographic collection, recognized the lack of knowledge about photo linen. Following their request to the head of the conservation department, Sandra Weerdenburg, the museum granted its collaboration for this research. Based on the above-mentioned argumentation for sampling the museum was also willing to provide sample material. For this purpose a 'Request for sampling' was written for and approved by the SMA in which the aim and relevance of sampling, the proposed analysis and requested samples were described.

The selection of photo linen works to be sampled was made in consultation with the two conservators of the SMA, Clara von Waldthausen (supervisor of this research) and the author. From the perspective of this research it was most important that the selected samples were with certainty photo linen. Since it was not well understood what the characteristics of photo linen were, identification of the material as photo linen was based on object documentation and visual examination of the works. A selection of at least two samples would be most useful for the purposes of this research since their outcomes could be compared, resulting in information about possible differences. To augment the chance on differing material compositions, preferably objects from different periods and makers should be sampled. From perspective of the museum on top of the foregoing requirements for samples, samples should preferably be taken from objects for which sample examination would be of direct use to help solve current conservation questions. Lastly, logistical considerations such as accessibility of the object for sampling and the availability of sampling material in an unobtrusive location of the object were of importance.

Three works from the SMA collection were made available for sampling:

1. Dibbets, Jan. "Perspective Correction – Diagonal/Crossed/Diagonal" (A-34587-1), 1967
2. Raetz, Markus. "Bett" (A-30960), 1970
3. Raetz, Markus. "Das Atelier" (A-30961), 1970. Reprinted in 1982

The work of Jan Dibbets is part of his Perspective Correction series and the work is a highly valued piece in the SMA collection. It is frequently exhibited and travels often. Characterization of the specific composition of this photo linen would help set preventive conservation guidelines for the object. Moreover, initial research indicates that all photographs in this series are made on the same type of photo linen.[68] This means analysis of this type of photo linen would probably provide specific information for the composition of all forty photographs in the series.[69]

The choice for sampling the two photo linen works from Raetz is also two-fold. Both objects were originally made in 1970. One of them was reprinted in 1982, supposedly on the same material.[70] Comparison of the two aims to indicate whether this is true. As these objects are extremely large and unrolling them is very time consuming, it was possible to sample then because the SMA has recently received a loan-request for these two objects. Including them in the survey and sampling could provide insight into whether

[67] ICOM, 2004: 7. See section 3.5, 3.6 and 3.9.
[68] SBMK, 2013: 16-17.
[69] Verhagen, 2014: 34-35. In The Netherlands at least five works from this series are present in museum collections. In total the series consisted of forty works.
[70] Stedelijk Museum Amsterdam, 2017 [B].

or not the loan-request would be honoured. The original installation requirements for these objects is that they are supposed to be hung on a wall with two clamps on the top corners with the textile hanging loosely bowed in the center. Object-documentation indicated that the artist bathed the textile in a glycerine bath to make the textile pliable to allow for the above-described installation.[71] However, at the moment the material is not sufficiently pliable to be installed in this manner.

A fourth sample was provided from the personal collection of Martin Jürgens, photograph conservator at the Rijksmuseum in Amsterdam. The sample originates from a piece of photo linen that is part of a supplier catalogue of "*ORWO Fotoleinen FL"*, produced in 1973. This sample was of interest for this study because it is the only sample of known origin and could be used as a reference for comparison of the other samples. Throughout this thesis the SMA samples will be referred to as "inventory number, artist", for example "A-34587-1, Dibbets". The ORWO samples will be referred to as "ORWO".

Sample-taking and preparation

The sampling locations were primarily selected based on the availability of material on an unobtrusive location where sampling would not hinder the physical stability of the object nor be visible. These locations were situated at the edges of the photo linen on the verso of the objects. The aim was to obtain sample material in which the complete layered structure of the photo linen was present and where the material was in the best chemical condition as possible. It was hoped that this would lead to the most decisive and comparable research outcomes. Therefore another location criterion was that the photo linen had not been directly exposed to external factors. This meant for the work of Dibbets, where the photo linen is stretched around a stretcher frame, that sampling took place from an underlying piece of photo linen on the verso of the stretcher frame, where bulk material was present. This sample consists of a non-image area and is completely white. The Raetz photographs consist of two strips of photo linen that are horizontally sewn together at the center of the image. The flat-lying seam is barely noticeable from the recto. This is where the samples were taken. Both these samples consisted of image areas.[72]

Tessa Rietveld took the samples in the presence of Clara von Waldthausen and the author. The sample-size was around 2,0 x 0.4 cm. These dimensions are large for sampling original material, but were decided upon because: 1. They were available, 2. It was important to make sure all the layers would be present, 3. Because it was deemed better to have a sample as clean as possible. If samples of the edge of the material were taken point 2 and 3 would have not been certain. As sampling was very time-consuming, the large sample size ensured repeatability of the analysis and the making of more than one cross-section if problems with a first cross-section occurred. Sample remnants will be saved to perform future research.

The desired size was measured onto the sampling location and the samples were cut using scissors and held in place using a dental tool and tweezers. Complete photographic documentation was made throughout the complete procedure to be kept with the object's documentation. The sample-size and sampling procedure were comparable for the ORWO sample from the collection of Martin Jürgens. In this case the author carried out sampling. These samples will be referred to as 'dry sample'.

Before examination could take place the samples needed to be prepared. The dry samples were used to examine the surface of the recto and verso of the photo linen and fibres from each sample were extruded to carry out fibre analysis. A piece of the dry samples was removed to produce cross-sections that would expose the layered build-up of

[71] Stedelijk Museum Amsterdam, 2017 [A].
[72] Stulik, 2010: 430. Derrick, 1999: 16.

the material. Since this procedure was never carried out with photo linen before it was not readily clear whether the procedure would result in usable cross-sections. However, in consultation with paintings conservators from the University of Amsterdam it was decided to follow common embedding practice used for embedding paint and canvas cross-sections.

Under a microscope, 1.0 x 4.0 mm pieces were cut from the samples using a scalpel from the inner edge of the linen. Embedding was carried out in Technovit 2000 LC, an in Ultraviolet (UV) light-curing resin. Interaction of the sampling material with embedding resin can occur when one of the components is reactive with it. Since there was no reason to expect interactions of the sample material with the resin, Technovit was chosen. After curing, the samples were polished wet using water on all sides, alternating in all directions. Care was taken to stop a few microns before the sample would be exposed to the surface as the gelatin and possible other components from the photo linen could swell and dissolve in water. Wet polishing was started with sanding paper of particle size 320 nm decreasing to 2400 nm. Next, dry polishing was carried out until the widest part of the sample was exposed using respectively sanding papers with particle size 2400 nm to 12000 nm. As a result useable cross-sections of the samples were produced.

Sample examination

In the first step of the examination, microscopy with crossed-polarized light was used to identify the substrate fibres. This fibre-analysis was carried out in cooperation with Bas van Velzen, paper conservator at the University of Amsterdam and lecturer of the course "Fibre-Analysis". Several fibres were loosened from a warp and a weft thread from every dry sample using pin-tools under a stereomicroscope. For each sample one microscope slide was prepared with the fibres from the warp thread and one microscope slide from the weft thread. A drop of 1:1 water-glycerol solution was added to the fibre before the cover slide was placed on top, in order to create an air-free environment and an even microscopic image free of air bubbles. Each slide with fibres was examined under a Zeiss Axio Lab A1 optical microscope at 100x magnification with a cross-polarization filter. Cross-polarized light can indicate thickness (or depths) in the fibre, and results in an image where colours represent different thicknesses. In fibre analysis this cross-polarization can be used to observe primary and secondary identification characteristics of natural and synthetic fibres by showing for instance their shape and surface texture.[73]

The second step in the examination of the samples was microscopic inspection of both the dry and embedded samples with an Axioplan 2 optical microscope. This microscopic examination was carried out with the help of RCE scientist Muriel Geldof. Microscopic photographs were made using the attached Craic Attestor 60-C microscope camera. The samples were examined using regular lighting for bright field and dark field microscopy and UV light (365 nm) at magnifications of 10x, 20x, 50x and 100x. UV light was used because this can provide information about the presence of fluorescing components, like pigments or optical brighteners.[74] The aim of microscopic examination was to obtain information about the physical structure of the samples.

The results of the fibre-analysis and optical microscopy functioned as a guideline for the Fourier transform infrared spectroscopy attenuated total reflection imaging (FTIR-ATR imaging) of the four cross-sections that followed. Decisions for the use of analytical techniques were made in consultation with RCE Scientist Suzan de Groot who also carried out FTIR-ATR imaging. This technique was used to identify the organic components in the samples and to create an image of where these components are located in the cross-section.

[73] Personal communication with Bas van Velzen, 11-05-2017.
[74] Stulik, 2010: 422.

Based on the results of the optical microscopy and the hypothesis that the bulk of material in the samples was of organic nature this technique seemed most useful to create initial understanding of their composition. The FTIR-ATR imaging was carried out with the use of a Perkin Elmer Spectrum 100 FTIR spectrometer equipped with a Spectrum Spotlight 400 FTIR microscope, 16x1 pixel linear Mercury Cadmium Telluride array detectors and a Perkin Elmer ATR imaging accessory with germanium crystal. The aim of the FTIR-ATR imaging was to obtain an overview of the present organic components and the physical structure of the samples.[75]

[75] Stulik, 2010: 426-428.

4. RESULTS

4.1 Introduction

In this chapter the results will be presented. The structure of this chapter is similar to that of chapter 3. The results will be discussed in order of increasing magnification used to obtain the results, starting with visual examination and lower magnifications in section 4.2 where the outcomes of the technical survey will be presented. In section 4.3 the outcomes of the different components of the materials analysis will be given. In order of the used magnification first the results of the fibre-analysis will be presented, followed by the results from the optical microscopy of the cross-sections, to conclude with the outcomes of FTIR-ATR imaging.

4.2 Technical survey

Introduction
During the technical survey information was obtained about the material characteristics and deterioration forms of photo linen.[76] To create an overview of the myriad of results they will be divided into two categories. The first category presents the results found on the general characteristics of photo linen. This category is divided in three sub-sections: image layer, image appearance and substrate. The second category presents the results concerning the deterioration forms of photo linen and is also divided into the sub-sections 'image layer' and 'substrate'. Within these sub-sections the observations are divided into chemical and physical deterioration forms. As a final component some secondary identification characteristics for photo linen, as obtained during the survey, will be included.

General characteristics of photo linen
Image appearance
Monochrome images of continuous tone
All examined photographic images were monochrome and had a continuous tone, as expected for silver gelatin material. [77] Both characteristics were found using magnification. The image areas ranged from light grey to black and exhibited the organically shaped, non-strictly bordered image characteristics of true photographic, continuous tone images.

Contrast
Contrast in photographic reflection prints relates to the range of tones, from the lightest grey to almost black, present in the print. In high-contrast images less grey tones are present between the lightest and darkest area than in a low-contrast image. In the literature review it was found that only medium gradation emulsions were used on photo linen, this means external factors, such as different processing chemicals or procedures influenced this contrast. This will be discussed in the next chapter.[78] Visual examination found that

[76] The technical survey forms contain sensitive information about the surveyed objects and are therefore not attached to this thesis. Upon request from the author and in consultation with the concerning institution they can (partly) be made available.
[77] Reilly, 2009: 63.
[78] Gristwood, 2007: 653.

the contrast of the photographic image varies per object and no clear categories could be observed upon visual examination. Some images appeared very hard and do not show much detail, whereas other images appeared softer and were finely detailed with superb texture expression.

Image tone
The overall image tone of the works varied. A visual distinction could be made into two categories: cold and warm tone images. Twenty-two out of the twenty-nine objects had a cold black image tone in the D-max (shadow) and midtone areas, whereas the others had a warmer, slightly brown tone in comparable areas. It must be noted that observation of the image tone was complicated by the colour of the D-min areas (highlights), provided by the substrate or pigmented layer that ranged from cold white (twenty-four works) to slightly warmer, yellowish tones (five works). For the objects with a warm D-min tone in five cases the verso had a colder white tone than the recto. As these observations could be made only when the verso was visible, it is not clear what the total number of objects was that share this characteristic. These observations will be discussed in the next chapter in combination with several deterioration forms.

Image layer
Thin coating
In all works the image layer was present as a thin coating on top of the textile substrate, following the weave and leaving the thread structure visible. Magnification was needed for its identification. Because this layer thinly coated all fibres, under 200x magnification a worm-like appearance was observed. As the layer is transparent in the non-image areas (since there is only binder present in these locations) it could best be seen in the midtone or dark areas where silver particles are present.

Evenness
All surveyed works had an overall and even image layer that was visible running up to the edges of the photo linen. Monochrome image areas were generally very even in the midtone and D-max areas. Exceptions were two works made by artist Gea Kalksma. They showed unevenness in the dark areas, exhibiting overall horizontal lighter streaks that coincide with shallow undulations in the fabric. Based on the findings from the literature review, it is expected that these might be related to folding of the material during processing (see section 5.3).

Finishing techniques
Onto the photographic image of thirteen works the artists applied other media. In eleven cases these media were applied locally and could be identified with visual examination. In seven cases a black, ink-like retouching medium was observed applied in streaks or larger areas in shadows. Two works were retouched with an opaque grey paint. Van den Berghe used a red marker to write text on his Oktober 1975 photograph. On three works translucent paint glazes were locally applied. On three objects also opaque paint layers were locally present.

The photographic images of two works were completely covered with translucent coloured glazes and opaque paint layer and could be mistaken for colour photographs or photomechanical prints. However, upon closer visual inspection it became clear that the glazes had a different appearance than the dye-clouds of colour photographs or grain

pattern of photomechanical processes.[79] The uneven borders of the different coloured areas could easily be detected: they did not completely follow the photographic image. With the use of magnification the paint glazes could be observed as partial colouring of the substrate, only present in the 'valleys' in the weave structure or also top of the highest surface areas.

Gloss

Four different gradations of surface gloss were observed on the works in raking light: matte, slight gloss, high gloss and very high gloss. Generally, the gloss was overall even. It was found that gloss differences could be due to the thickness of the emulsion or the application of media such as matte or glossy translucent (coloured) glazes. Where opaque paint layers were applied to the photographic image the surface exhibited a slight gloss.

In fifteen works a slight overall gloss was observed, that was most likely the natural gloss of the gelatin on the textured substrate. A matte surface observed on the work of Henk Tas that, under magnification, showed a very thin emulsion compared to the fifteen works with a slight overall gloss. A partially matte surface was observed in the works of Guus Groenendijk, who applied matte, translucent paint glazes. A high gloss was observed on the work of Roland van den Berghe (Oktober 1975) that was coated with a glossy, transparent orange coating. Application marks were visible at the sides of the object. A comparable gloss was found on Dibbets' work at BVB. At the edges of this work a subtle, somewhat more saturated line was observed at the edge of the work that marked the border between the high gloss surface and slight gloss of the photo linen at the edges. A very high, sparkling gloss was observed in the two works from Aernout Mik at the VAM. No application marks were observed here. However, the photo linen sounded and felt significantly stiffer than all other surveyed photo linen and upon touching the material sounded like touching printing paper.

Hairline cracks

Parallel hairline cracks were observed in four works of Gea Kalksma who used wooden stretcher frames to mount the photo linen. The cracks always only followed one direction of the threads and occurred at the edges of the photo linen where the photo linen was stretched around the frame vertically along the top and bottom edge, closely to the corners of the frame. These hairline cracks are presented under the header 'general characteristics of the image layer' since it is expected that they were caused during the stretching of the photo linen onto the stretcher frame and therefore is inherent to the production of the work of art instead due to deterioration (see chapter 5.3).

Substrate

Weave

For all assessed works their textile substrate was readily visible without magnification. With magnification the non-image side of the thirteen works in which the verso was visible, showed no signs of a coating in all works. The textile of all substrates was a plain-weave: alternating one warp and one weft thread. The density of the weave varied from a very open 13/13 threads per cm in one exceptional case to 30/30 threads per cm in seven works. Generally the weave exhibited a very even texture. In nine cases incidental knots were observed in the threads, which disfigures the evenness of monochrome image areas.

[79] Dye-clouds in chromogenic colour photographs are organically shaped, small clouds in cyan, magenta and yellow. These cannot be observed with the naked eye, magnification is needed. A grain-pattern is observable in photomechanical prints. The term refers to the non-continuous tone of the image that in this case has a fine, irregular dot pattern.

In exceptional cases on these knots no emulsion was present at all. No selvedges were observed during assessment.[80]

Stiffness
The photo linen of twenty-five works was found to be stiff to the extent that, when non-mounted, it could move statically bus was not supple. Exception was the substrate of the work of Madelon Hooykaas, this was very flexible and pliable. Due to their format the flexibility of the three overall adhered photographs on photo linen could not be examined. For the works of Raetz, meant to hang loosely so that the upper edge curves down loosely in pleats when installed on a wall, the fact that they are no longer this pliable means that their original installation method is lost. From the object documentation in the SMA database it is known that originally the photo linen (after processing) was too stiff to be installed as the artist wanted. To make the fabric more pliable the artist bathed the photo linen in glycerine to make them flexible.[81] Apparently, this flexibility has been lost over time. That photo linen was initially stiff and not easily pliable was confirmed in personal communication with maker of three of the surveyed works Aernout Mik.[82]

Cusping
Cusping was observed in several works where the photo linen was mounted onto a stretcher frame. Cusping occurs when a fabric is mounted onto a stretcher frame and attached at the sides of this frame. Internal stresses on the fabric can become large due to the extent of stretching or method of mounting and it is pulled nearer to the edge at the parts where it is attached to the frame with staples or nails. This can result in a repeated arch-like pattern visible in the weave structure that coincides with the placing of the staples.[83] The works of Beckman, Dibbets (BVB), two works of Dibbets at the SMA and the works of van den Berghe exhibited cusping.

Planarity
Planar deformations in the form of creasing of the textile as a material intrinsic or processing characteristic was observed in the form of an overall fine wrinkled pattern of mounted photo linen in two works. For the three-dimensional works folds and creases in the photo linen were inherent to their format.

Deterioration forms of photo linen
Image layer: Chemical deterioration
Overall yellowing
An overall yellow/brown discoloration was observed in the D-min areas of seven works. The yellowing provided the image with a somewhat blotchy, but overall warm tone. Observing overall yellowing was difficult, since it was not known what the original tone of the D-min areas was. However, upon examination of both the recto and verso a colour difference between the recto and verso could be observed in seven works, where the recto was warmer in tone than the verso. Since because of the presence of a pigmented layer or transparent impregnation the colour of the recto would always be whiter or comparable to the verso this difference could be attributed to discoloration. Since these observations

[80] Selvedges are the outer edges of a woven cloth and are formed during the weaving process. They can be the same or a different weave than the body of the weave.
[81] Stedelijk Museum Amsterdam. Complete Object Description, Record Number 10352 [A], 2017.
[82] Personal communication with Aernout Mik, 01-04-2017.
[83] Buckley,2006.

could be made only when the verso was visible, it is not clear what the total number of objects was that share this characteristic.

For overall yellowing of the image areas (midtone and D-max) no decisive observations could be made since the initial image tone and contrast of these specific images and photo linen in general was not known.

Local yellowing

Local yellowing was also encountered in seven works in the D-min areas. The types of yellowing ranged from edge yellowing, yellowing only of the central part of the photo linen, yellowing in small, spot formations all-over the image and local yellowing in large organic shapes.

Orange/pink discoloration & density loss

Localized orange/pink image discoloration in image areas, visible as an irregular pattern where the image density was reduced, was observed twice. Similar discoloration and density loss was observed in other works made by Hooykaas and Raetz. However, here the edges of the area were less defined. Since in the case of Hooykaas' work discoloration was observed in a transition area between D-min and D-max it could clearly be observed that only the image area exhibited discoloration. A test with a swab confirmed that in the works of Raetz the discoloured areas coincided with the presence of a lot of loose grime.

Silver mirroring

A common deterioration form for silver gelatin DOP's is silver mirroring. This occurs when silver particles are oxidized into invisible silver ions that can travel through the binder and be reduced to metallic silver again at the surface. In raking light this is visible as a metallic bluish to silver sheen.[84] During the survey this was encountered twice, on works from Dibbets and Raetz. In both cases the silver mirroring exhibited a very low sheen and was visible, as is normal, in the dark image areas where the silver image density is heavier. The silver mirroring was in both cases accompanied by other form of decay such as local yellowing.

Orange/brown staining

In two cases an unusual phenomenon was encountered. Along the right side of Raetz' 'Tonbandknauel' orange/brown staining was observed. The stains penetrated the substrate and have a dark brown center that under magnification is visible as a transparent brown crystalline material. Around the center an orange ring is present. They do not fluoresce under UV radiation. In the areas where these spots occur the image silver changed from the typical black DOP silver to colloidal silver judging from its orange/brown colour. Visually comparable stains, with crystalline accretions, were observed on 'Bett', made by the same artist in the same period. However, the stains are bigger and do not penetrate the substrate, but have the same build-up and discoloration effect in the midtone areas.

Image layer: Physical deterioration

Emulsion loss

In nineteen works emulsion losses were observed. In fourteen of these cases the loss can best be described as abrasion. These abrasions were exclusively found on the corners and along the edges of the photo linen, where it was folded around the round edge of the wooden stretcher frame and where it was vulnerable to physical contact. As can be

[84] Weaver, 2008: 11.

expected from abraded material, the image material was mainly lost in the high parts of the weave structure where chafing was more likely.

In four objects deep scratches were observed in which the image layer was completely removed. Minimal delamination in the form of emulsion loss without any indications of abrasion (such as rolled gelatin at the edges of the loss), correlating to the weave structure was observed on three objects and must not be considered structural.

Accretions
In six works coloured accretions were observed on the photo linen works. Bright red, yellow and blue linear deposits were visible on the surface, often where impact of an object, for instance against a painted wall or transportation cart, may have taken place. The accretions were present at the corners of stretcher frames or next to deformations, punctures or scratches of the substrate, but were also observed in otherwise unharmed areas.

Surface grime
The presence of other foreign material in the form of surface grime was observed in twenty works to some extent. The findings ranged from powdery dust and small particles in the weave structure to embedded, grey handling marks in the center of the edges and incidental insect faeces.

Substrate: Chemical deterioration
Overall yellowing
Overall yellowing of the verso of the substrate was only observed in two objects and coincided with many other forms of deterioration.

Local yellowing
Three types of local yellowing were observed. These are already mentioned in the section describing local yellowing of the image layer since upon examination it became clear that in these cases the yellowing penetrated both the image layer and substrate. One type of local yellowing was only observed on the verso in one object. Here strictly bordered square yellowing was observed where the object was in contact with a pressure-sensitive tape attached to its packaging materials.

Discoloration of fraying edges
One case of yellowing of a fraying edge of photo linen was observed along the edges of a tear.

Substrate: Physical deterioration
Planar deformations
Planar deformation in the fabric was encountered in different forms. Buckling at the edges for non-mounted photo linen and buckling in the corners and overall for mounted photo linen was observed.[85] Mainly the non-mounted photo linen works show stiff folds along the edges.

Mechanical damages
Mechanical damages were the most frequently observed damages for the substrates. These damages were primarily punctures and tears of the fabric and ranged from small punctures

[85] Keyser, 1984: 1.

to a five centimetre long tear and a one centimetre high three-cornered tear. In two instances an impact took place but did not puncture or tear the fabric and only left it permanently expanded.

Secondary identification characteristics of photo linen
Next to surveying of the material qualities of photo linen structural information on the photo linen works such as their size and format was also collected. These serve as secondary identification characteristics and will therefore be shortly touched upon in this paragraph. Most of the works are larger than photographs on paper during the same period. Seventeen works were mounted onto a wooden stretcher frame. This appears to be by far the most popular method of presentation of photographs on photo linen and, in combination with the textile substrate it provides the objects with a painting-like appearance. For works on stretcher frame, the dimensions ranged from 30x20x1.5cm to 244x108x1.5 cm, with an average size of around 120x120x1.5 cm.

4.3 Materials Analysis

Fibre-analysis
With fibre-analysis fibres from the warp and weft threads of all samples were identified as cotton fibres. This identification was based on the observation of primary identification characteristics of cotton. The fibres all have a characteristic wrench and, in cross-polarized light, cotton fibres show thickness transitions as a yellow area turning into a blue area with a red line in-between. When the sample is turned 90˚ the yellow and blue exchange places. These images are exemplary for all samples. A lumen could be identified in the center of the now flat cotton fibres as a darker line. This lumen is the central hollow tube inside the originally round fibre.[86] Upon flattening of the fibre the lumen collapsed, resulting in a thin area in the center of the flat fibre that is seen as a somewhat darker line in crossed-polarized light.

These observations correspond to the observations that were made of the cross-sections of all samples. Seen from the side, flattened cotton fibres have an ear-like shape because of the collapsed lumen.[87] This shape was found in cross-sections of the samples. The observed translucency corresponds to the high crystallinity of common cotton fibres of about 75%.[88] Based on these two examination methods the identification of all fibres as cotton is conclusive.

It was noted during microscopic examination of the fibres that the shape of the fibres is fairly round. This could indicate that the fibres were mercerized.[89] Mercerization involving caustic soda to swell the fibres, makes them stronger, more absorbent, and increases their lustre.[90] Examination with cross-polarized light could however not confirm this. Elemental analysis of the fibres, such as gas-chromatography mass-spectroscopy (GC-MS), could provide decisive information.

Optical microscopy of photo linen cross-sections
As is similar for photographic materials on paper, the textile substrate was found to be relatively thick compared to the layers coated onto it. The substrates of all four samples

[86] Landi, 1998: 21.
[87] Personal communication with Bas van Velzen, 11-05-2017.
[88] Personal communication with Bas van Velzen, 11-05-2017.
[89] Ibidem.
[90] Landi, 1998: 21.

had a thickness of 200-250µm. In all cross-sections but "A-34587, Dibbets, on top of the substrate a translucent layer of around 10 µm was observed. This layer completely followed the topography of the substrate. In "A-34587, Dibbets" this layer could not clearly be observed. However, using UV radiation a comparable layer could be seen in this sample.

In samples "A-30960, Raetz", "A-30961, Raetz" in bright field, dark field and UV radiation black particles were observed throughout this layer. Due to these particles it could be seen that the translucent layer filled the small valleys in the surface as far as 10-20 micrometres for the first two samples. In "ORWO" the particles could also be observed, however with somewhat more trouble. Here the layer was only situated on top of the substrate without penetrating it to any extent. In the fourth sample, "A34587, Dibbets", these particles were not observed. This complicated the visual identification of the transition between the substrate and layers on top, as was also the case to observe the translucent layer at all. It is most likely that the translucent layer is the emulsion, and the black particles are silver particles. This is consistent with the fact that all but "A-34587, Dibbets" consist of image areas, where silver should indeed be present.

No indications for the presence of a pigmented layer were observed. The microscopic images were compared to cross-sections of DOP's with different compositions: a thick baryta layer, thin baryta layer and no baryta layer. Based on this comparison it became clear that any white, pigmented material would have been readily distinguishable as opaque and clearly bordered from the other component. Moreover, a close similarity was observed between the DOP without a baryta and the photo linen cross sections in the thickness of the emulsion and how it follows the surface topography.

In many photographs in regular light a light line along the top of the translucent layer (along the top edge of the cross-sections) was observed. Visually this closely resembled a white layer on top of the layered structure of the photo linen. However, upon closer examination it became clear that different light scattering in these areas most likely brought about the colour difference. This was likely caused by a slight irregularity in the polished surface of the cross-section, just where the sample ends and the embedding material starts. This interpretation was backed-up by the observation of the cross-sections in UV light, where no colour differences corresponding to the 'lines' observed in regular light could be observed. Moreover, the presence of a pigmented layer on top of the emulsion would not be logical.

FTIR-ATR imaging

From the results presented in 3.2.1 and 3.2.2 it is clear that the substrate of all samples is made of the same material. This is consistent with the findings of the FTIR-ATR imaging analysis that identified all substrates to exist of cellulose fibres. The main component of processed cotton fibres is at least 88% alpha cellulose, whereas if it were linen the cellulose-content would be remarkably lower and the amount of other components such as lignin, hemicellulose and waxes would be higher.[91]

The similarity between the substrates of the samples did not hold for the pre-treatment. The samples can be divided into two groups based on their layered build-up. The first group consists of samples "A-30960, Raetz" and "A-30961, Raetz". Directly on top of the substrate a protein layer is situated, visible in blue. This layer could be identified as gelatin based on the characteristic Amide I (at 1635 cm^{-1}) and Amide II (at 1532 cm^{-1}) peaks in the spectrum, together with the additional Amide peaks at 1448, 1240 cm^{-1}.[92] This finding is consistent with the hypothesis that photo linen substrates are coated with a

[91] Landi, 1998: 21-22.
[92] Stulik [B], 2013: 35.

gelatin silver halide emulsion and the findings of the optical microscopy. Using the scale-bar in the imaging results it can be seen that the gelatin penetrated the voids between the cotton fibres until 50-70 micrometres under the surface. In sample "A-30960, Raetz" the gelatin is also present on the verso of the sample, where it penetrates the fibres evenly deep as on the recto.

The second group consist of samples "A-34587, Dibbets" and "ORWO". Here also a protein layer was found that based on the Amide peaks in their spectra could also be identified as gelatin.[93] In addition polyvinyl acetate (PVAc) was detected and can be seen in the imaging results in pink. This material is a colourless, thermoplastic resin that is commonly applied as a water-dispersed resin. After drying, it produces a clear film with an almost invisible bond line that has good water resistance. The material is commonly used as a fabric finishing.[94] The PVAc was not present as a layer coated onto the substrate, but as an impregnation of the first 50-70 µm of the substrate filling the voids between the fibres. The voids more to the center of the threads show in red in the imaging results. They are filled with the embedding material that could penetrate these areas before curing.

[93] Stulik, 2013 [B]: 35.
[94] 'Polyvinyl acetate' *Cameo*.

5. DISCUSSION

5.1 Introduction

In this chapter the results presented in chapters 2 and 4 will be discussed. In section 5.2 a reflection on the legitimacy of the research methods and accuracy of the results will be provided. This will be followed by a discussion of the results from each research component in the light of what they tell about the material characteristics and aging qualities of photo linen and what questions are still left unanswered. In section 5.3 the findings of the literature review will be discussed. In section 5.4 the same will follow for the results of materials analysis. Finally, in section 5.5 the outcomes of the technical survey will be discussed.

5.2 Accuracy of the research methods and the results

The three research components were devised to complement each other. It was hoped that this would lead to a comprehensive characterization of the materials' general characteristics and aging qualities. This worked out as expected and a lot of information was obtained on different aspects of photo linen. However, since all three research components were carried out simultaneously, upon growing insight it was sometimes too late to include options to relate the theoretical findings from the literature review to the survey and materials analysis. When there would have been time to start with the literature review and after its completion start the two other components this would have led to an even more complete characterisation of the material.

All care was taken to obtain trustworthy results. In the literature review all sources were carefully weighed for their accuracy and, where possible, primary sources were consulted. A critical note on the results from the survey relates to the organic development of the insight into material and deterioration qualities of photo linen. Because of this growing insight, objects assessed later in the process were examined with more knowledge and scrutiny than the early objects. Due to time and organizational constraints re-assessment of these earlier objects could not be fitted into the research. This means that the results are not completely consistent in terms of details and frequency of the observed phenomena. Moreover, the size of the survey had to be fitted to the available time, but a larger selection of works would have led to more reliable results. Shortcomings like the fact that the recto and verso could not always be fully inspected would have less of an impact on the results in a bigger survey.

Upon progression in the research project insight also grew into the possibilities to quantify several of the qualitative observations made with visual observation. Quantitative data about certain material aspects would have been more provable and relatable, such as measurements of the observed gloss differences. However, since this research presents a first exploration of photo linen, the gained insight into the general material characteristics and which of these characteristics can be quantified in the future already greatly improve the current knowledge (see section 6.3).

Last notice on the results of the survey is that UV inspection of the surveyed objects was carried out with the use of a Dinolite. This is fitted with UV light of wavelengths 390-400 nm. After several surveys it was decided not to use this as the clear plastic cap that the Dinolite is fitted with allows visible light to pollute the image. The fact

that non-fluorescing surfaces also appear blue supports this. Therefore no meaningful data related to fluorescing components could be acquired during the survey.

The execution of all three components in the 'materials analysis' section and the interpretation of the results were carried out with the help of scientists to guarantee their accuracy. The combined results of this section do not provide a complete image of the (layered) composition of photo linen. A characterisation of the non-organic components would be necessary for al full characterization. Due to the above-described progressing insights in relation to time restraints unfortunately this component was not included in this research (see section 6.3).

5.3 Literature review

The combination of theoretical information from patents and more applied information in the form of supplier information and handbooks resulted in a substantive overview of the history, composition and production of photo linen that was of big help to interpret the findings from the survey and materials analysis.

Substrates and pre-treatment of the substrates
For the type of substrate of modern photo linen no limitations were found in theoretical accounts on photo linen products in patents. However, in product information only the use of cotton in a plain weave was described. Therefore it must be kept in mind that different types of fabrics can be encountered.

More issues relate to the pre-treatment of the substrate. For modern photo linen the use of two types of pre-treatments was found, although based on the findings it cannot be stated with certainty that these two were exclusively used. The application process of the pre-treatment using a pigmented layer was not found. Whether both recto and verso were coated and how viscous the coating was upon application (did it form a thick coating on top or did it mostly function as impregnation of the top fibres and formed a thin layer on the surface?) is not known.

The lack of information about the first pre-treatment makes it impossible to constitute what visual signifiers could be for the presence of a pigmented layer. For instance, substantiating that there must be a visual indication, such as warm-tones D-min areas on a substrate that shows a cooler tone on the verso that indicate a coloured baryta, can be disproven by the fact that yellowing of the emulsion or a possible coating can also be responsible for this tone. As will be seen in the section discussing the outcomes of the survey, finding characteristics for this division was also unsuccessful in practice. This can mean that no photo linen with a pigmented layer was encountered, but can also point towards the fact that the visual differences between the two types of pre-treatments might be very small.

Although this is stated nowhere specifically, both these pre-treatments must have also increased the chemical stability of many images on photo linen, by making sure less chemicals were absorbed during processing that could partially remain in the processed and dried material, leading to chemical instability. This was confirmed by the fact that no indications for major problems with residual chemicals were encountered during surveying.

Emulsion
The impregnated substrate was coated using regular coating methods and therefore the size of the photo linen, just as for photo papers, is limited in width to fit in the coating machine.

What the maximum width of photo linen was could not be established during this research. The maximum named in product information is 127 cm, however, the maximum observed height was 133.5 cm in Raetz' "Das Atelier". Since the material of this work corresponded to all physical characteristics of photo linen during surveying, it appears to be the case that some manufacturers could produce larger products. For identification purposes, it is good to keep in mind that when a photograph on a textile substrate with a significantly larger width than 127 cm is encountered this might not be commercial photo linen, but hand-coated textile. In this case application marks, uneven monochrome image areas and gloss differences might be observable.

The literature review confirmed that photo linen is a silver halide material, resulting in monochrome, continuous tone images. Use was made of emulsions of medium gradation. This means contrast differences in images on photo linen are not due to the presence of emulsions of different gradations, but to external factors like the quality of the negative, exposure time and intensity, the used processing chemicals and the processing time and agitation.

The exact type of silver halides used did not become clear from the literature review. Gayer stated that bromide was found on sheets and chlorobromide on rolls of photo linen. The resulting images would have, respectively, a cold or warmer tone.[95] It was hoped that based on the outcomes of the survey this could be confirmed. Warm and cold tone images were indeed encountered, but unfortunately no relation could be detected between image tone and dimensions of the photo linen. This could be due to the fact that like for contrast, there are a wide variety of factors responsible for the image tone such as the type of processing chemicals used, toning or deterioration of the silver image. These factors make that it cannot be concluded at all that the warmer and cold tone images that were encountered are indeed a result of the use of different silver halides.

Not only silver halide emulsions could have been applied, the substrates could also be coated with Diazotype emulsions. These emulsions resulted in purple and off-white images and are upon visual examination easily mistaken for silver halide photographs. Moreover, these products were mainly in use for professional purposes according to literature and are less likely to be encountered in institutional collections.[96]

5.4 Technical survey

The information gathered in the technical survey confirmed a lot of the theoretical findings about photo linen from the literature review, for instance relating to the production and composition. But the information also expanded on this by providing insight into the extent variations in substrates and image characteristics occur and its aging qualities.

General characteristics of photo linen

Image appearance

Visual examination confirmed that all photographic images of the surveyed objects are monochrome and have a continuous tone corresponding to the use of silver halide materials. In line with what is described in the section above about the characteristics of the applied emulsions, both the contrast and image tone were less consistent.[97] Therefore,

[95] Hodgson, 2007: 643.
[96] Stulik, 2013 [B]: 16
[97] Lambrecht, 2007: 665-670.

making general statements about the contrast and tone of photo linen images remains difficult and a larger number of objects on photo linen would have to be surveyed.

Although variations were observed in the colour of the D-min areas (and the verso), it did not become clear whether this, or other visual indications, could help to identify what type of pre-treatment was used for the substrate. This is unfortunately most likely a result of the simultaneously carried out research components: very late in the process it was confirmed that pre-treatment of photo linen substrates with a pigmented layer were indeed used, therefore no active attention was given to this point during surveying. Also based on the photograph documentation and notes made during surveying no indications for the presence of a pigmented layer could be traced.

Image layer

When viewed under normal light, in all objects the weave structure and fibres were visible under the very evenly applied emulsion. Based on these observations, the patent descriptions of the different types of photo linen and the dating of the objects, it can be concluded that all objects were made on modern photo linen varieties. Since it became apparent that the emulsion was very even and machine-coated, the streaks observed in several works by Kalksma, as well as shallow horizontal folds of the substrate in the work of De Vries Robbé can most likely be ascribed to the way they were processed: folded processing was recommended by suppliers. This could have led to uneven processing of the image and permanent folds in the photo linen upon drying.

What varied more than evenness, was the surface gloss. The gloss of photo linen is difficult to use as a general characteristic for photo linen because the surface structure of the textile, thickness of the coating and the application of finishing techniques such as translucent coloured glazes all influence the gloss, which makes it difficult to set a baseline.

The hairline cracks observed in works from Kalksma are expected to be a result of the way the photo linen was mounted onto the stretcher frame. Since they only appeared in the direction that the canvas was stretched (pulled) around the frame it is likely that the crack appeared as a result of too much tension on the gelatin upon stretching of the photo linen around the stretcher frame. When comparing the characteristic elasticity of stretchable woven cotton to that of the more brittle gelatin, it is likely that the fabric can stretch further than the gelatin layer. This could result in the hairline cracks that are visible probably due to breakage of the gelatin structure at these areas of intense stretching.[98] However, more testing is needed to confirm this idea.

This is true also for the cusping in the substrate. The cusping is the result of stresses in the fabric, and could be the result of wet mounting of the photo linen that then shrunk upon drying.[99] In this case cusping would be a technique inherent characteristic. However, it can also be a result of relative humidity (RH) changes on the substrate and increase over time.[100] It is important to be clear on their origin (if they are technique inherent or a form of deterioration) prior to undertaking active conservation treatment and to ensure that conservation treatment does not result in damage.

Substrate

Also, all photo linen, except for Hooykaas, has certain stiffness. Part of the stiffness can be accounted for by the pre-treatment of the substrate. However, upon aging of the component materials this stiffness can also increase. Also, chemical processes causing chain-scission

[98] Swan, 2010: 538.
[99] Eastop and Timár-Balázsy, 1998: 25.
[100] Ibidem.

in the protein polymers of the gelatin, the cellulose chains of the textile and polymer components of the impregnation make them more brittle, resulting in increased stiffness.[101] To find to what extent the original composition or the aging play a part in the stiffness of a certain photo linen is difficult. Therefore it is in any case important to realise that as these materials age, the initial properties of photo linen might change, like its water-resistance and resistance to high temperatures might change.

Deterioration forms of photo linen

Chemical deterioration of the image layer

The chemical forms of deterioration surveyed are similar to those encountered on DOP's, as expected. The most common reason for deterioration of the image layer, or more specifically the silver particles, is oxidation. The bundles of so-called 'filamentary' silver created in chemical development have a relatively large surface area compared to their mass and are therefore prone to oxidation. Pollutants from the air or packaging material can provide oxidizing agents. However, images consisting of filamentary silver are a lot less susceptible to visible shifts in tone and detail loss than their physically developed counterparts.[102] Oxidation works as follows: small particles of the filamentary image silver (Ag^0) get oxidized into invisible silver ions (Ag^+). These ions can travel through the gelatin and can be reduced into visible silver again. This reduction can take place in different forms.

When the ions travel to the surface and get reduced this causes silver mirroring. This was observed two times on photo linen during the survey.[103] In both cases the silver mirroring coincided with other types of deterioration such as local yellowing, which is an indication that at some point in their lifetime the objects were exposed to detrimental conditions. However, the fact 'only' two objects show silver mirroring, considering the fact that all objects have been exposed to air, and therefore to pollutants, is noteworthy. This might be an indication of the fact that they have always been kept in ideal conditions, or that the material is less prone to silver mirroring than was expected based on the knowledge of this phenomenon on DOP's. This might have to do with properties of the emulsion that makes it difficult for the ions to migrate to the surface, for instance the surface topography or the presence of hardening agents. More research would be needed to understand this.

The second visual form of oxidation was observed as local and overall yellowing and (slight) density loss in image areas (D-max and midtone). Both types were observed on photo linen. Yellowing can occur when the silver ions react with sulphur to form yellow/brown silver sulphide or other reducing agents. Depending on the size and shape of the resulting particle, the overall image tone can shift to yellow or brownish. However, observation of this type of silver oxidation is often complicated by the fact that all-over yellowing, but also local yellowing of D-min and midtone areas can have other causes too or might be the result of a combination of factors. The type of silver halide used in the emulsion, residual processing chemicals, aging and discoloration of the gelatin, discoloration of for instance a mounting adhesive or even the impregnation or an intended warm tone image or substrate can all also influence the gradation of yellowness of photo linen.[104]

In the last visual form of oxidation, silver ions are reduced back into metallic silver briefly. The ions reduce to smaller particles of silver, known as colloidal silver, and have a

[101] Eastop and Timár-Balázsy, 1998: 25. Mills and White, 1994: 89.
[102] Feldman, 2010: 189-190.
[103] Swan, 2010: 545.
[104] Weaver, 2008: 26-30.

warm orange tone. It is expected that this is what caused the discoloration/density loss in the work of Hooykaas. This discoloration appears as density loss only in the image areas. It can therefore be concluded that the silver has oxidized. Interesting is that the discoloration encountered on Raetz' "Bett" and "Tonbandknauel" show similar orange discolorations and density loss. However, these areas are strictly bordered as opposed to what was observed on Hooykaas' work. Both might be silver oxidation caused by reducing agents, but the strictly bordered formation is most likely caused by contamination with liquid oxidizing chemicals and the other upon contact with oxidizing gases.

The observed brown staining with a crystalline center also appeared to have an oxidizing, or better said, bleaching effect of the image silver. It is not understood what caused this staining in Raetz' "Bett" and "Tonbandknauel". The crystalline center does not seem to indicate rust as the source, although the stains do have a typical colour for 'foxing' caused by iron particles embedded in the textile or introduced from tap water during washing. Therefore it could also be that, as the Book and Paper Catalog describes, this 'foxing' appearance is for instance caused by contamination with some sort of brownish (processing) chemical or, insect faeces.[105] Whatever the cause may be it is clear that the staining material contained a strong oxidizing agent that oxidized the silver in these areas.[106]

What does this information about the chemical deterioration of the image layer tell about its susceptibilities? Since the common emulsions were present and the observed deterioration forms of the image layer are very consistent with what we know about DOP's, it can be concluded that their susceptibilities are comparable, at least to a large extent. Gelatin, like many other organic polymers, can form chromophores upon aging. These are coloured molecules that consist of oxidised pieced of the polymer chain that came loose due to chain-scission processes.[107] This can happen under the influence of high energy in the form of radiation, temperature or light, pollutants or high humidity.[108] Upon progress of these processes gelatin can become more soluble or brittle. For the silver image their stability depends on internal as well as external factors: the processing steps and particle size of the silver influence its stability, as well as moisture, heat and pollutants.[109]

Physical deterioration of the image layer

The physical deterioration of the image layer is mainly observed in the form of emulsion losses. The losses are not 'clean' like would be the case when adhesion-failure between the image layer and substrate took place, but all had the form of abrasions and scratches. A logical explanation for the many emulsion losses can be found in the rough surface of the photo linen, the large dimensions of many of the works and the fact that the preferred format for the presentation of photo linen is stretched around a stretcher frame. Objects easily touch the corners and edges of these works during handling and then abrade the heavily textured surface of the photo linen.

For the many accretions encountered during the survey the same factors are at play. The fact that a lot of surface grime was found is also due to the highly textured surface. Small particles get easily embedded. Next to aesthetic implications, dust can be hygroscopic which can accelerate aging processes and some components can have an oxidizing character. The influence of surface grime on photo linen should thus not be

[105] Bertalan, 1992.
[106] Mills and White, 1994: 89.
[107] Weaver, 2008: 4.
[108] Reilly, 2013: 45.
[109] Weaver, 2008: 9.

underestimated. Since it is established that the emulsion is easily abraded care should be taken when removing the grime.

Chemical deterioration of the substrate
Visual examination indicated that the deterioration forms of the substrate are primarily physical. The chemical stability of the substrate is likely largely accounted for by the fact that photographic manufacturers who produced photo linen had experience with photographic substrates. Photographic substrates need to be chemically pure and free of for instance lignin and other components that can interact with the image layer.[110]

The only chemical deterioration forms were overall yellowing of the substrate once and local yellowing in several cases. Although it could not be confirmed with visual examination what type of fibres were used for the substrates, all types of fibres are built up from polymers that upon (local or overall) contact with oxidizing agents, high energy in the form of light or radiation and moisture can be influenced by chain-scission as described above for gelatin. This often results in discolouration and other alterations in the material properties such as increased brittleness. Especially for cellulosic substrates, acidity is also regarded as a degrading factor.[111]

Physical deterioration of the substrate
Planar deformations of photo linen mounted onto a stretcher frame were regularly encountered in the survey. The photo linen was no longer tightly stretched, but showed permanent expansion. It is found that natural fibres will expand upon contact with moisture, but after they have reached their yield point will not regain their original shape, but exhibit limited elastic recovery.[112] This will leave the textile permanently expanded and can occur due to cycling RH.[113] However, more or different factors might be at play, and these factors might differ for different types of textile. More research into the type of substrates in photo linen and their physical reaction to moisture, temperature and pollutants is needed to completely understand the phenomenon.

The second type of physical deterioration observed were mechanical damages in the form of tears and punctures of the photo linen. Like most mechanical damages of the image layer, this was also primarily encountered on photo linen mounted onto a stretcher frame and can be accounted for by the fact that the dimensions of the works are generally large and the photo linen is not supported or protected from the verso.

5.5 Materials analysis

The results from the materials analysis proved to be mainly interesting in the light of whether the theoretical information was indeed used commercially. It must be noted that only a small selection of four samples were analysed, providing limited insight. However, no major anomalies were found between the information from the literature review and the materials analysis, which does verify the accuracy of the results from both components.

[110] Reilly, 2013: 44-45.
[111] Ibidem.
[112] Eastop and Timár-Balázsy, 1998: 25. Landi, 1998: 22.
[113] Eastop and Timár-Balázsy, 1998: 23.

Fibre-analysis

Only cotton was found in the four photo linen samples. This is in accordance with product information and is not unsurprising since cotton does have properties that make it very suitable as a substrate for photo linen. Chemically cotton is very suited as a substrate for photographic images since after processing it may contains 88-96% alpha cellulose. This chemical composition compares to the rag papers, made from cellulose fibres with high alpha cellulose content, that have a long history as preferred paper substrates for photographs since they are inert towards the image layer.[114] Such purified substrates are less prone to deterioration caused by the high energy of temperature and light, high humidity, acidity and oxidations.[115] Physical properties of cotton are that it does not stretch easily; upon 2% expansion due to contact with moisture (RH changes outside 45-65%), the elastic recovery of cotton is 74%.[116] Because of these properties it is described as very dimensionally stable material for objects that are stored and exhibited in hanging positions.[117]

With microscopic examination no decisive results could be acquired on whether the cotton fibres were mercerized. This would alter the properties of the cotton, by altering the original crystalline structure of the cellulose.[118] This change would result in increased lustre, strength and swelling power.[119] To find conclusive results analytical methods to find remnant the alkaline mercerization treatment or physical testing that indicates the altered physical properties should be conducted. However, before such testing is carried out it must be kept in mind that the results will not hold for all photo linen products since it was found that different types of fibres could be used for the substrate.

Optical microscopy of photo linen cross-sections and FTIR-ATR imaging

With optical microscopy a better insight was gained into the layered structure of photo linen. Based on visual comparison of the photo linen cross-sections to different types of DOP's a visual resemblance was found for DOP's without a baryta. All other findings backed up the hypothesis that the photo linen cross-sections consist of only two (visible) layers: the substrate and the baryta directly on top. No pigmented components could be observed under any magnification. This indicates that all four samples are most likely examples of photo linen pre-treated with the one-layer impregnation that turns out to be transparent and not visible upon visual or microscopic examination.

The FTIR-ATR findings partially confirmed the microscopy findings. For all samples it was evident based on the combined results from microscopy and FTIR-ATR that the substrates were pre-treated and the emulsion applied afterwards. The findings for gelatin and PVAc in the impregnation are also consistent with the patents from 1966 and 1973 that described this procedure. However, it must be noted that with FTIR-ATR imaging no paraffin was found in all samples, although, according to patent information, this was without exception used as hydrophobic component of the transparent impregnation and paraffin is an organic hydrocarbon material. This is most likely due to the fact that the FTIR needs a presence of at least 3% in mass of the component material to be detected. This hypothesis is backed up by the fact that for the "ORWO" sample, for which the patent from 1973 directly provides information, also no paraffin was detected although it could be stated with a high degree of certainty that it is contained in this sample

[114] Reilly, 2013: 44.
[115] Reilly, 2013: 45.
[116] Ibid.: 34.
[117] Ibidem.
[118] Eastop, 1998: 30.
[119] Ibid.: 21.

according to patent information. Based on these combined findings it must be concluded that during this research no practical clues were found that pre-treatment of photo linen substrates with pigmented layer were commercially used. In order to trace pigmented layers, SEM-EDX analysis of the sample would be needed.

One last remark on the results is that since FTIR-ATR imaging could not confirm the observed black particles to be the image silver and definitely rule out the presence of any barium sulphate or titanium oxide that to whatever reason did not become visible during microscopy, a very small margin of error needs to be taken into account for the conclusions from this section. Although visual examination and the FTIR-ATR imaging results did not provide any visual indication for inconsistencies with regards to the conclusions, only analysis could provide conclusive answers.

6. CONCLUSION

6.1 Material characteristics and aging qualities of photo linen

Photo linen has a long history and can be divided into three groups based on it's dating: early (last quarter 1800's-1930's), early modern (1930's-1960's) and modern photo linen (1960's- end 1990's). In this research the focus was on modern photo linen. This is the most likely photo linen to be encountered since between 1903 and 1963 no accounts for the availability of photo linen were found for non-professional use.

Commonly, dense, even, plain-woven, highly purified cotton substrates were used for modern photo linen. To improve the physical properties of these substrates they were pre-treated. This pre-treatment was carried out in at least two different ways that both resulted in flexible, translucent (when backlit) and water-resistant products in which the weave structure and fibres stayed clearly visible. The first pre-treatment consisted of a pigmented coating of the substrate, composed of gelatin, barium sulphate and titanium oxide. No indications for the use of this pre-treatment could be traced during practical examination of photo linen during this research. The second pre-treatment was a transparent impregnation consisting of a hydrophilic (paraffin) and hydrophobic (gelatin or PVAc) component. The commercial use of this impregnation was confirmed using analysis.

Photo linen is coated with a regular hardened silver halide emulsion of medium gradation. For the image this means that they are always monochrome, continuous tone images. The images can be of varying contrast and tone. Characteristics of the image layer in general are that the emulsion is present as a ± 10 μm thick, evenly and overall applied coating, resulting in even monochrome image areas and images that can be developed through the edges of the material. When examined with magnification, the emulsion exhibits worm-like shapes.

The most popular presentation form of photo linen is around a wooden stretcher frame, but the material can be used loose or sewn into three-dimensional shapes. Finishing techniques, like translucent or opaque coloured paint are commonly encountered on photo linen. This can give photo linen the appearance of a colour photograph or mechanical print. Identification of application marks can help identify the presence of finishing techniques.

Photo linen and DOP's have the same emulsion and therefore the chemical forms of deterioration of their image layer are comparable. The chemically developed filamentary silver is prone to oxidation. Oxidation can be observed with the naked eye as overall yellowing and local yellowing in midtone and D-max areas or a pink/orange discoloration coinciding with density loss as well as silver mirroring. However, local and overall yellowing should not be directly be ascribed to oxidation since often more factors are at play, such as discoloration of the gelatin. The substrate of photo linen is commonly relatively resistant to chemical aging and inert towards the image layer due to its highly purified nature.

Since the chemical composition of photo linen is fairly similar to that of DOP's the susceptibilities of the materials are fairly similar. For the silver holds that the processing steps and particle size of the silver influence its inherent stability. Both the silver and the gelatin can degrade under the influence of pollutants, moisture and high energies in the form of light and invisible radiation. For cellulosic substrates acidity must be added to the list. For objects that suffered from chemical deterioration is must be expected that their properties changed, resulting for instance in lowered water-resistance, heat resistance and increased brittleness.

Physical deterioration of photo linen has two main forms that are both closely related to the physical characteristics of the substrate. One common form is the permanent expansion of the substrate, visible mainly when it is no longer tightly stretched around a stretcher frame. This phenomenon is most likely caused by high intensity RH changes outside 45%-65% for cellulosic fibres. The second form of physical damages is mechanical damage. This is a big risk for both the image layer and substrate of photo linen. Due to the large dimensions and the fact that photo linen is often stretched around stretcher frames, corners, edges, but also central parts of the objects get easily impacted when handled. The textile is often not protected on the verso and gets easily punctured or torn. The heavily textured surface gets easily abraded upon impact, resulting in loss of the image layer, and collects a lot of loose grime.

6.2 Recommendations for future research

This research answered a lot of questions. However, it also provided insight into what is still not known about photo linen. A few of the most relevant steps for future research are:

1. Carrying out scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) on the four cross-sections used in this research. SEM-EDX needs to be carried out to confirm that the black particles observed in the optical microscopy of the cross-sections in this research are indeed silver particles and it can rule out the presence of pigments.

2. Surveying of more works on photo linen to obtain accurate data about the frequency of different deterioration forms. This could improve insight into the susceptibilities of the material, might provide more visual clues for identification and could be used (together with the findings of this research) to create a damage atlas for photo linen that can be consulted when deterioration on photo linen is encountered.

   One point of focus for further surveying should be to obtain information about visible clues to identify the two different pre-treatments found in this research. If these clues are indeed found they should be confirmed with techniques such as the non-invasive use of a photospectometer to measure a colour difference between recto and verso, or invasive analysis with FTIR-ATR imaging and SEM-EDX.

3. During this research results were not quantified. To create a firmer grip on the identification characteristics, future research into ways to quantify information about gloss, contrast, tone and visual clues for the chemical condition of all components would be interesting.

4. When several of the above proposed research steps are taken, comprehensive preventive (and maybe recommendations for active) conservation guidelines can be written up. This could be preceded by research into the current preventive conservation practices for photo linen since during this research it was found that this might be a valuable source for practical information and ideas.

5. Research building further on the availability of different photo linen with the aim to create an online accessible ‘photo linen library’ where product information about

all different types of photo linen can be consulted to function as a reference and research application.

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