Wet Cleaning Synthetic Fibres:
A Preliminary Investigation into the Effects of Conservation Detergents on Soiled Synthetic Test Fabrics.

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Abstract

Although wet cleaning is common practice within textile conservation, limited research has been undertaken on its use on twentieth-century synthetic fabrics, which are gradually entering museum collections and in turn conservation studios. This dissertation research focuses on the effects of wet cleaning synthetic fibres, looking in detail at soil removal and detergent choice. Standardised wet cleaning tests were conducted on artificially soiled and aged test specimens, to include four different fibres: cellulose acetate, viscose rayon, nylon and polyester. An anionic and a non-ionic detergent were used in the wet cleaning tests to determine the effectiveness of the wash solution and evaluate the effects of conservation wet cleaning on the fibre's tensile strength. Both colour readings and tensile strength testing were used to assess the differences before and after cleaning. The results confirmed that the wet cleaning process had little effect on the tensile strength for nylon or polyester but a noticeable change in elongation was evident for both cellulose acetate and viscose rayon after all wet cleaning tests. The soil removal specimens produced varied results between soiling and fibres. While certain stains were removed by the detergent baths on some fibres they were not removed on others. It was found that acetate and polyester were the most improved after wet cleaning and anionic detergent was the most effective at soil removal overall. These results confirmed that detergent selection should be based not only on the fibre type but soiling and stains should also be considered. This research concludes with recommendations and guidelines for conservators looking to wet clean synthetic fibres.

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Introduction

Twentieth-century man-made materials, such as synthetic fibres, are still relatively new in terms of textile fibre history. While natural fibres, to include cotton and silk, have been used for thousands of years,[1] textiles made from man-made fibres have only been in production for the last century.[2]

Synthetic fibres, otherwise known as man-made fibres[3], are becoming more widespread within museum collections and textile exhibitions.[4] This increase reflects the rise of man-made fibre production for the British textile industry, which currently accounts for more than half of all textile fibres used throughout the world.[5,6] With such large numbers of synthetic fibres in production it is 'inevitable that there is an increase in synthetic materials entering museum collections.'[7]

At present, few interventive treatments have been carried out on objects containing synthetic fibres and this is evident in the lack of available literature. However, as the materials age and their conditions deteriorate, more interventive measures will be necessary to improve the state of the fibres and slow down degradation processes. This means that research is required in this area to aid conservators in the preservation of these modern textile fibres. Evidence shows that objects containing synthetic fibres 'have already begun to deteriorate in museums and other collections',[8] and 'the growing use of synthetic polymers has created problems for museums and many items in their collections'.[9]

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[1] Jennifer Harris, *5000 Years of Textiles* (London: The British Museum Press, 2010), 54-55.

[2] J. Gordon Cook, Handbook of Textile Fibres, Vol. II – Man-Made Fibres (Cambridge: Woodhead Publishing Ltd, 2001), 9.

[3] Throughout this dissertation *synthetic fibres* will be used as a collective term (unless otherwise stated) when referring to any man-made fibres, which include semi-synthetic or regenerated fibres. A description of semi-synthetic fibres is given in Chapter 1, 1.2.

[4] Sarah Howard, 'Working with Synthetic Fibres: The Response of Textile Conservation to Twentieth-Century Dress', in *Textile Conservation: Advances in Practice*, ed. Frances Lennard and Patricia Ewer, 221 (Oxford: Butterworth-Heinemann, 2010).

[5] British Man-Made Fibres Federation, *Better Living with Man-Made Fibres* (London: British Man-Made Fibres Federation, 1986.

[6] CIRFS, 'About Man-Made Fibres,' European Man-Made Fibres Association, 2013 http://www.cirfs.org/ManmadeFibres/AboutManmadeFibres.aspx (Accessed 11.06.2013).

[7] Howard, 221.

[8] Lisa M. Ferreira, 'Manufactured-Fiber Conservation: A Cause for Concern?', in *The Textile Specialty Group Postprints Vol. 9 (1999), Papers Delivered at the Textiles Sessions of AIC's 26th Annual Meeting in St. Louis, MO*, 11-18 (St. Louis, MO: The Textile Specialty Group of the AIC, 1999).

[9] Ferreire,11.

One commonly used interventive treatment for the conservation of historical textiles is wet cleaning.[10] This cleaning practice uses water to help remove soiling and stains in a gentle and controlled process, making it suitable for aged and fragile objects. Additional cleaning agents, to include surface-active agents (or detergents), are often added to water to help improve cleaning efficiency.[11]

Conservation wet cleaning can be a useful treatment for historic textiles and the process is widely used for a varied range of textile fibres and objects. A large amount of research has been conducted on wet cleaning artefacts made from natural fibres, which includes information on different detergents for natural fibre types and categories of soiling.[12,13] When a historic textile is deemed suitable for wet cleaning an informed decision can therefore be made in selecting an appropriate detergent and washing method.

As mentioned there is limited literature available on the practice of wet cleaning for synthetic fibres and where case studies have been published there is little detailed information about the decisions made in relation to processes and materials used. There is also no literature available to date which advises on the most suitable detergent(s) for wet cleaning synthetic fibres. This highlights the fact that more research into wet cleaning would be beneficial.

The purpose of this research is to determine whether wet cleaning is a safe and appropriate treatment for synthetics with a particular aim of identifying the type of conservation detergent most suitable for the fibres and soiling.

New, undyed, standard soiled fabrics have been selected as test samples and include two synthetic fabrics and two semi-synthetic or regenerated fabrics. The samples will undergo artificial ageing prior to controlled conservation wet cleaning tests, using one anionic and one non-ionic detergent. The effects of wet cleaning and the selected detergents will be evaluated by examining changes to the visual and physical properties of the fabric samples.

Variations in colour, dimension, soil removal and tensile strength will be analysed and the findings will be compared with untreated control samples. The selected methods of

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[10] Ágnes Tímár-Balázsy, 'Wet Cleaning of Historical Textiles: Surfactants and Other Wash Bath Additives', *Reviews in Conservation*, *IIC* 1 (2000): 46.

[11] Ágnes Tímár-Balázsy and Dinah Eastop, *Chemical Principles of Textile Conservation* (Oxford: Butterworth-Heinemann, 1998), 194.

[12] Tímár-Balázsy and Eastop.

[13] Mary W. Ballard, 'Update: Detergency and the Aqueous Cleaning of Antique Textiles', in *The Textile Specialty Group Postprints Vol. 19 (2009). Papers delivered at the Textile Subgroup Session, AIC's 37th Annual Meeting in Los Angeles, CA,* 89-101. (Los Angeles, CA: The Textile Speciality Group of the AIC, cd format, 2010),

assessment include visual examination (aided by magnification), weave density measurements, colour change through the use of a Chroma meter and tensile testing.

It was intended that this research would identify some useful findings to benefit other conservators looking to clean synthetic textiles. The aims and objectives will now follow.

Aims and Objectives

The aims of this research were to:

- Determine whether wet cleaning is a safe and appropriate treatment for synthetics
- Identify the type of conservation detergent most suitable for the fibres and soiling present
- Provide basic guidelines for other conservators looking to clean objects made from synthetic fibres

These aims were met through the following objectives:

- Review the existing literature for synthetic fibres and wet cleaning practices to provide context for this research and to identify the types of soiling and detergents to be tested during the investigation
- Use textile science publications to investigate synthetic fibre properties in relation to wet strength to gain an understanding of the similarities and differences between fibre types and to discover how the fibres may be affected by wet cleaning tests
- Conduct pre-tests to determine the stains and wet cleaning procedure appropriate for testing and to select the required length of time for artificially ageing the soiled test specimens
- Design a standardised wet cleaning method to test the effectiveness of the chosen detergents in relation to soil removal and to identify any differences to the fibres' tensile strength caused by the detergents or washing procedure
- Analyse the results through visual and physical assessment criteria, to include colour measurements and tensile strength tests
- Draw conclusions from the test results to help make recommendations for conservators on the wet cleaning of synthetic fibres and to identify further research needed

Chapter 1 - Literature Review

1.1. Introduction

A review of literature was undertaken with the initial aim of highlighting an area of potential research, which in turn provided the context for this dissertation. From examining the available literature it was clear that limited research had been undertaken into conservation treatments, and particularly wet cleaning, of textile objects made from, and containing, synthetic or semi-synthetic fibres (hereafter referred to collectively as synthetic or man-made).

This chapter brings together and reviews key sources of literature relating to synthetic fibres and the practice of conservation wet cleaning, using a selection of published and unpublished works to aid discussion. Both conservation literature and textile science sources will be analysed to provide information on the fibres, detergents and processes used in this research dissertation.

The literature review is divided into three sections. The first part examines synthetic fibres and their increasing presence within textile collections. A brief explanation of the different fibre types will also be provided. Wet cleaning research and treatments will then be evaluated, focusing on the choice of detergents available to textile conservators. Publications concerning the removal of soiling and staining will be considered. Lastly a number of case studies involving past object treatments of textile artefacts containing synthetic fibres will be reviewed.

The focus of this research is to investigate the effects of wet cleaning and conservation detergents on synthetic fibres and while there are many valuable articles published on the subject of wet cleaning natural fibres these will not be studied in detail and only referred to when necessary.

1.2. Synthetic Fibres

Synthetic fibres fall into two separate groups. Semi-synthetic fibres form the first group which are produced by regeneration or modification of natural polymer fibres, such as viscose rayon and cellulose acetate. The second group, produced from petrochemicals, are entirely synthetic polymers and include polyester and nylon fibres.[14] While semi-synthetic fibres are not strictly true synthetic polymers they exhibit similar properties (for example in

[14] Tímár-Balázsy and Eastop, 55.

their production process) and differ to natural fibres. These fibre types and their properties will be discussed further in Chapter 2.

Man-made fibres have been in production since the beginning of the twentieth-century, with viscose rayon (the first semi-synthetic fibre) being produced in 1904 and synthetic fibres, such as nylon, being manufactured from the end of the 1920s.[15] However, twentieth-century synthetics fibres are a relatively new addition to museum collections and it was not until the late 1980s to early 1990s that research into the conservation of synthetic materials began.[16,17]

Since then, a number of conservation conferences have been dedicated to modern materials, including *Twentieth Century Materials, Testing and Textile Conservation* presented by Harper's Ferry Regional Textile Group in 1988,[18] the 1991 Canadian Conservation Institute's (CCI) symposium *Saving the Twentieth-Century: The Conservation of Modern Materials* held in Ottawa, Canada[19] and more recently in 2005, the Arts and Humanities Research Council (AHRC) Research Centre for Textile Conservation and Textile Studies second annual conference *The Future of the Twentieth Century: Collecting, Interpreting and Conserving Modern Materials*.[20]

However, even with modern materials slowly gaining recognition, the focus is still on plastic materials, such as cellulose nitrate and polyvinylchloride (PVC), which are known to be inherently unstable.[21,22] A number of published articles as well as unpublished research

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[15] Cook, 2001.

[16] Patricia Ewer and Frances Lennard, 'Scientific Developments', in *Textile Conservation: Advances in Practice*, ed. Frances Lennard and Patricia Ewer, 232 (Oxford: Butterworth-Heinemann, 2010).

[17] Yvonne Shashoua, 'Conservation of Plastics: Is it Possible Today?', in *Plastics: Looking at the Future and Learning from the Past,* ed. Brenda Keneghan and Louise Egan, 12. (London: Archetype Publications, 2008).

[18] Ewer and Lennard, 232.

[19] David W. Grattan, ed., *Saving the Twentieth Century: The Conservation of Modern Materials, Proceedings of a Conference, Symposium '91, Ottawa, Canada, 15-20 September 1991* (Ottawa: CCI, 1993).

[20] Cordelia Rogerson and Paul Garside, eds., *The Future of the 20th Century: Collecting, Interpreting and Conserving Modern Materials. AHRC Research Centre for Textile Conservation and Textile Studies, Second Annual Conference, 26-28 July 2005, Postprints* (London: Archetype Publications Ltd, 2006).

[21] Chris Paulocik and R. Scott Williams, 'Modern Materials in Costume Collections: A Collaboration Between Scientist and Conservator', in *Strengthening the Bond: Science and Textiles, Preprints of the North American Textile Conservation Conference, 5-6 April 2002*, 77-89 (Philadelphia: The North American Textile Conservation Conference, 2002).

[22] Alexandra Palmer, 'A Bomb in the Collection: Researching and Exhibiting Early 20th Century Fashion', in *The Future of the 20th Century: Collecting, Interpreting and Conserving Modern Materials. AHRC Research Centre for Textile Conservation and Textile Studies, Second Annual Conference, 26-28 July 2005, Postprints,* ed. by Cordelia Rogerson and Paul Garside, 41-47 (London: Archetype Publications Ltd, 2006).

projects highlight the issues of degrading modern synthetic materials. These however focus on textile objects in the form of laminated plastic coatings and finishes rather than textile fibres.[23,24,25,26] It is evident from the minimal amount of published sources on synthetic textile fibres that they are still under-researched in terms of their degradation processes and conservation treatments. As Ferreira states in her 1999 paper: 'Future research into any area of manufactured-fiber conservation would add to the existing body of literature simply because it is relatively small compared to that which exists for objects composed of natural fibres.'[27]

The fact that textiles made from, or containing, synthetic fibres are still comparatively new and still in good condition may be a reason for this lack of research but it is also possible that these objects are less frequently displayed (and therefore less commonly treated) or less treatments are undertaken due to limited knowledge in this area.[28]
While conservators cannot currently be certain of how or when these fibres will degrade it is probable that more remedial treatments will be needed as the objects age and their conditions alter. Cleaning treatments, such as wet cleaning, are therefore still likely to be used to help remove soiling and stains from synthetic textile objects.

1.3. Wet Cleaning

The treatment of wet cleaning is widely used in textile conservation to both remove harmful deterioration products and improve the fibres flexibility.[29] It can be an extremely beneficial process, enhancing the overall stability, handling and appearance of historical textiles.[30]

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[23] Howard, 221-226.

[24] Nancy Kerr and Jane Batcheller, 'Degradation of Polyurethanes in 20th-Century Museum Textiles', in *Saving the Twentieth Century: The Conservation of Modern Materials, Proceedings of a Conference, Symposium '91, Ottawa, Canada, 15-20 September 1991*, ed. David W. Grattan, 189-206 (Ottawa: CCI, 1993).

[25] Doon L. Lovett, 'The Deterioration of Polyurethane (PUR) Foam With Reference to Foam-Laminated 1960s Dresses', (MA Dissertation, Textile Conservation Centre, University of Southampton, 2003).

[26] Sarah Glenn, 'An Investigation into the Conservation of Spacesuits and High-Altitude Pressure Suits', (MA Dissertation, Textile Conservation Centre, University of Southampton, 2008).

[27] Ferreira, 17.

[28] Ferreira, 12.

[29] Tímár-Balázsy, 'Wet Cleaning of Historical Textiles', 47.

[30] Season Tse, 'Wash Water Quality Requirements for Textile Conservation: An Overview of Canadian Conservation Institute Research', in *Strengthening the Bond: Science and Textiles, Preprints of the North American Textile Conservation Conference, 5-6 April 2002,* 143. (Philadelphia: The North American Textile Conservation Conference, 2002).

Much literature is available on the practice of wet cleaning, ranging from past conservation treatment case studies to reviews of cleaning processes, research into the effects of water quality and temperature, and efficiency of detergents and other washing agents.[31,32,33,]

While the majority offer useful information relevant to this dissertation research, only those focusing on detergency and soil removal will be evaluated in more detail. Included in these are a number of investigations into wet cleaning effects on standard soiled natural fibres.

1.3.1. Detergent Choice in Conservation

Detergents (also known as surfactants) play an important role in the wet cleaning of textile artefacts. They help wet out the textile by reducing the surface tension of water, aid soil removal and can keep dirt particles suspended in the wash solution, preventing them from returning to the fibres.[34]

The detergents used in conservation wet cleaning fall into two groups: anionic and non-ionic. Both groups are organic molecules with a polar hydrophilic (water-attracting) head and a non-polar hydrophobic (water-repelling) tail, which work together to improve cleaning efficiency. However, the two groups possess a number of different properties (e.g. non-ionics are better at solubilising fatty soiling while anionics have better overall cleaning power), which can make one detergent more desirable for a particular object.[35]

Once it is decided that an object is fit for wet cleaning a detergent will be selected. The type of detergent is often chosen for its suitability to the textile fibres and the soiling present.[36] It is considered that anionic detergents are more effective for cellulosic fibres while non-ionic detergents are used for proteinaceous fibres.[37,38] As semi-synthetic fibres are cellulosic it would seem likely that an anionic detergent would be the most appropriate choice. Mills and White describe how nylon 'may be thought of as a synthetic equivalent of proteins',[39] which would suggest a non-ionic detergent may be more efficient for synthetic polymer fibres.

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[31] Tímár-Balázsy and Eastop.

[32] Tse, 143-151.

[33] Tímár-Balázsy, 'Wet Cleaning of Historical Textiles', 46-63.

[34] Tímár-Balázsy, 'Wet Cleaning of Historical Textiles', 48.

[35] Jane Lewis and Dinah Eastop. 'Mixtures of Anionic and Non-Ionic Surfactants for Wet-Cleaning Historic Textiles: A Preliminary Evaluation with Standard Soiled Wool and Cotton Test Fabrics', *The* Conservator 25, no. 1 (2001): 74.

[36] Lennard, Frances and Patricia Ewer, 'Remedial Conservation,' in *Textile Conservation: Advances in Practice*, ed. Frances Lennard and Patricia Ewer, 143 (Oxford: Butterworth-Heinemann, 2010).

[37] Lewis & Eastop, 73.

[38] Centre for Textile Conservation, 'Principles and Practice: Developing Skills Semester 2 Session: Detergency Handout', *MPhil Textile Conservation Course Handout,* 23 January 2012.

[39] John Mills and Raymond White, *The Organic Chemistry of Museum Objects, Second Edition* (Oxford: Butterworth-Heinemann, 1999), 135.

However, there are currently no recommendations for a specific detergent type to be used with synthetic or semi-synthetic fibres, an area highlighted by Gamper in her 2012 dissertation.[40] Although Ballard raises the point that: ‘With these new synthetic fabrics and finishes, it is especially useful to revisit surfactant selection,’[41] there appears to be very little discussion throughout the paper of suitable detergents for synthetic fabrics.

Even though the textile object’s composition and condition should influence a conservator in selecting a suitable detergent, it has been recognised that over the past few decades many studios tended to use predominantly one detergent for all objects: ‘see the popularity of Orvus WA in the USA and Synperonic N in the UK.’[42] Tímár-Balázsy goes on to state that: ‘The method of choosing particular surfactants and washing solutions according to the specific need of the object to be treated, or using then in combination is still rare.’[43]

This is supported by the many previous wet cleaning treatments, to include the case studies published in Tímár-Balázsy and Eastop’s *Chemical Principles of Textile Conservation*, which report the use of non-ionic detergent, namely Synperonic N.[44] This detergent was used for all objects and fibre types but no explanation for the choice was provided. In their 2004 paper Fields et al. stated that Synperonic N was the primary surfactant used in conservation throughout the United Kingdom becoming ‘the surfactant of choice, as it was the only surfactant recommended by a scientist (Plenderleith 1956) and has proved highly efficient on cotton and wool.’[45]

In 2000, however, Synperonic N was phased out due to environmental concerns and a number of research projects were carried out to find substitute detergents. These investigations tested a selection of anionic and non-ionic detergents on soiled test fabrics, comparing their cleaning properties.[46,47,48] As a result of this research the number of

[40] Charlotte Gamper, ‘Viscose Rayon: An Absorbing Problem. An Investigation into the Impact Conservation Wet Cleaning Treatments have on Historic Woven Viscose Rayon Fabrics; with a Supplementary Analysis of Current Techniques for Identifying Man-Made Fibres’ (MPhil Dissertation, Centre for Textile Conservation, University of Glasgow, 2012), 9-13.

[41] Ballard, 89.

[42] Tímár-Balázsy, ‘Wet Cleaning of Historical Textiles’, 59.

[43] Tímár-Balázsy, ‘Wet Cleaning of Historical Textiles’, 59.

[44] Tímár-Balázsy and Eastop.

[45] John A. Fields et al., ‘Finding Substitutes for Synperonic N’, *JAIC*, Vol. 43, No. 1, Spring (2004): 55-73.

[46] Fields et al., 55.

[47] Rebecca Tinkham and Nancy Kerr, ‘Effectiveness of Soil Removal by Two New Nonionic Surfactants, Orvus WA Paste, and Surfactant Blends’, in *The Textile Specialty Group Postprints Vol. 11 (2001), Papers Delivered at the Textiles Sessions of AIC's 29th Annual Meeting in Dallas, TX*, 47-58, (Dallas, TX: The Textile Specialty Group of the AIC, 2001).

[48] Lewis & Eastop, 73-89.

detergents available for wet cleaning has increased with fewer studios using only one detergent and conservators making conscious decisions to select detergents appropriate for individual objects, taking 'into account the fibres of the textile, nature of the dirt […] and the foaming property of the detergent.'[49]

While Lewis and Eastop, and Fields et al. examined the effects on wool and cotton fabrics Tinkham and Kerr included nylon and polyester along with cotton samples stating that 'many historic textile collections are now accumulating garments and household textiles made from synthetic fibres in addition to natural fibres.'[50] This is one of the few publications investigating the effects of different detergents on true synthetic fibres. Their results showed that the anionic detergent was more effective at removing soiling on both natural and synthetic fibres than the non-ionic,[51] which conflicted with the 1977 findings of Patterson and Grindstaff who found that anionics produced very little effect on soiled polyester samples.[52]

The contrasting results may be due to the different surfactants tested or changes (and improvements) to the detergents during the twenty year time frame. However, the type of soiling present on the textile fabrics are also likely to have affected the cleaning efficiency of the tested detergents as different detergent types are more effective at removing different soiling. This aspect will now be examined in more detail.

1.3.2. Soiling and Staining

While fibre type is often the main factor in selecting an appropriate wash solution, detergency choice can also be based on the type of soiling present, such as the use of anionic detergents for acidic stains.[53]

As outlined in Ballard's paper detergent manufacturers divide soiling and staining into six categories: particulate soil, water soluble soil, oily or greasy soil, fruit or beverage stains, protein or starch based stains, and odours.[54] The materials science and technology institution EMPA provide similar classifications in their evaluation of detergents and washing processes but list microorganisms (bacteria, fungi, etc.) as a soiling category instead of odours.[55]

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[49] Tímár-Balázsy, 'Wet Cleaning of Historical Textiles', 54.
[50] Tinkham and Kerr, 48.
[51] Tinkham and Kerr, 52-54.
[52] H. T. Patterson and T. H. Grindstaff, 'Soil Release by Textile Surfaces', in *Surface Characteristics of Fibres and Textiles Part II*, ed. M. J. Schick, 445-494 (New York: Marcel Dekker Inc, 1977).
[53] Tímár-Balázsy and Eastop, 237-241.
[54] Ballard, 89.
[55] EMPA Test Materials, 'Evaluation of Detergents and Washing Processes with Artificially Soiled

EMPA states ‘that the diverse soilings behave differently with washing. Whilst *water-soluble salts*, for instance, are easily removed with water, *oily and greasy soilings* are emulsified with the interfacially active components of the detergents’.[56] This shows how the choice of detergent can affect the cleaning of soiled textiles and the information can be used to help conservators identify a suitable wash solution (using water with or without detergent) for the particular staining.

While it may be useful to categorise soiling in this way it appears that the soiling on historical artefacts is more complex than six main groups. Conservation literary sources, such as Tímár-Balázsy and Eastop’s *Soiling on Historical Textiles* chapter in the *Chemical Principles of Textile Conservation* textbook, advise how ‘Soiling can be classified according to its source, its potential to cause damage to textiles (harmfulness), its form and the possible methods of removal.’[57] They list 13 different types of potentially damaging dirt, most of which are summarised in the research previously undertaken by Tímár-Balázsy and Mátéfy, where they investigated the effect of stains and stain removal on historical textiles.[58]

However, this large and varied range of soils and stains is simplified when an object is selected for wet cleaning. While it is important to be able to identify the soiling present it appears that certain types of soiling have similar washing behaviours, therefore enabling them to be cleaned effectively with the same, or similar, detergent.[59] Conservation research has also been completed to offer advice on the most efficient detergent type (anionic or non-ionic) for removal of some common stains found on historic textile objects.[60] It should be noted that these act as guidelines only and additional factors, such as fibre type, fabric finishes and the object’s age, should also be considered as they can affect the detergents cleaning properties.

From reviewing the literature it appears that a number of specific stains and soiling types are frequently used in commercially soiled test fabrics, both for manufacture and conservation purposes. These reflect either the most common or problematic (in terms of their removal by detergent) stains found on textile fibres. Carbon black or soot is regularly used in soil

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Fabrics’, http://www.empa-testmaterials.ch/data/publications/en.evaluationofdetergentsandwashingprocesseswithartificiallysoiledfabrics.pdf. (accessed 24 March 2013).

56 EMPA, online.

57 Tímár-Balázsy and Eastop, 157-160.

58 Ágnes Tímár-Balázsy and Györk Mátéfy, ‘Effects of Stains and Stain Removal on Historical Textiles’, in *ICOM-CC 10th Triennial Meeting, Washington D.C, 22-27 August 1993, Preprints,* ed. Janet Bridgland, 330-335 (London: James and James, 1993).

59 EMPA, online.

60 Tímár-Balázsy and Eastop, 237-241.

removal research and is often referenced in published conservation papers.[61,62] Oily and greasy soiling has also been thoroughly investigated to help evaluate home laundry detergents, as it is absorbed into textile fibres.[63] While Ballard comments that 'such oily soiling common to home laundry is uncommon in museums,'[64] it is possible with the increase of synthetic fibres into textile collections that these stains may start to become more frequent as synthetics are known to attract and hold oily stains.[65] Patterson and Grindstaff's experiment to remove fatty soiling from different fibre types found that oily stains were removed well from natural fibres but very little effect was noticed on synthetics, particularly polyester fibres.[66]

The literature summarised in the wet cleaning section above will aid in the selection of stains to be used for this research and will help to identify a number of appropriate conservation detergents. The publications investigating the effects of wet cleaning on natural fibres will also be used in the design of a standardised wash procedure. These aspects are outlined in the methodology section in Chapter 3.

1.4. Conservation Treatments and Case Studies Relating to Synthetic Fibres

While a small selection of literature is available on the conservation of objects consisting of semi-synthetic fibres (namely viscose rayon and acetate), there appears to be very few studies that concentrate on the pure synthetic fibres, such as nylon or polyester.[67,68,69]

It is not clear whether conservation treatments of these synthetics are not currently being carried out in textile conservation studios, in the same manner as semi-synthetic objects, or if the treatments are not considered beneficial to the conservation world and are therefore

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[61] Tarja Reponen, 'The Effects of Conservation Wet Cleaning on Standard Soiled Wool Fabrics: Some Experimental Work', in *ICOM-CC 10th Triennial Meeting, Washington D.C, 22-27 August 1993, Preprints,* ed. Janet Bridgland, 321-326 (London: James and James, 1993).

[62] Tímár-Balázsy and Mátéfy, 330.

[63] Ballard, 90.

[64] Ballard 90.

[65] Kathryn L. Hatch, *Textile Science* (Minneapolis: West Publishing Company, 1993), 206-218.

[66] Patterson and Grindstaff, 445-494.

[67] Emma Telford, 'Treating Early Regenerated Cellulose Textiles: Two Case Histories', in *Saving the Twentieth Century: The Conservation of Modern Materials, Proceedings of a Conference, Symposium '91, Ottawa, Canada, 15-20 September 1991*, ed. David W. Grattan, 207-212 (Ottawa: CCI, 1993).

[68] Elizabeth-Anne Haldane, 'Surreal Semi-Synthetics', *V&A Conservation Journal,* Spring 2007, Issue 55, http://www.vam.ac.uk/content/journals/conservation-journal/issue-55/surreal-semi-synthetics/ (accessed 03 March 2013).

[69] Frances Hartog, 'Costume Cleaning Conundrums', *V&A Conservation Journal,* Spring 2008, Issue 56, http://www.vam.ac.uk/content/journals/conservation-journal/issue-56/costume-cleaning-conundrums/ (accessed 08 March 2013).

not available in published form at this time. A number of articles citing the conservation of semi-synthetic fibres will now be reviewed, with several referring to wet cleaning treatments that were carried out as part of the conservation.

Elizabeth-Anne Haldane's 2007 *Surreal Semi-synthetics* article for the Victoria and Albert Museum (V&A) discusses how a number of costumes were identified as containing semi-synthetic fibres from circa 1930s. Details are provided about the history and production of these fibres yet while Haldane states that: 'It is also particularly important to identify man-made fabrics prior to conservation treatment as they often cannot be treated in the same manner as natural materials' no information is provided on the conservation treatments undertaken or the differences in treating man-made fibres to natural based objects.[70]

In Emma Telford's paper *Treating Early Regenerated Cellulose Textiles* given at the CCI conference in 1991, the treatment of a cuprammonium (cupro) rayon dress dated to circa 1912 is recorded. Telford states that man-made fibres had not been researched or documented much in terms of conservation and this is still the situation two decades later.[71] She outlines a case for and against wet cleaning the object and the treatment was deemed unsuitable due to the dyes not being wash fast. The author also notes the poor tensile strength and reduced wet strength of rayon fibres, with care needed for handling when wet.[72] During this research a sacrificial 1920s viscose rayon kimono was tested to determine the effects of water on the tensile strength. The kimono was given a 'standard' wet cleaning treatment using the non-ionic detergent Synperonic N. Unfortunately, no rationale was provided for the reasons behind this choice. Telford remarks that once the object was 'wetted out, the textile contracted quickly in both the warp and weft directions.' However, the results show that no loss of strength had occurred.[73]

Another paper presented at the 1991 CCI conference documented the conservation of a twentieth-century rubberised raincoat designed by Mary Quant, which was undertaken by Clare Stoughton-Harris as part of a postgraduate diploma report. The raincoat contained a mix of natural and synthetic fibres, to include viscose rayon, acrylic and a cellulose acetate lining. The conservation involved a wet cleaning treatment to both remove degradation products and improve the aesthetic qualities by relaxing the fibres.[74] Synperonic N was

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[70] Haldane, online.

[71] Telford, 207.

[72] Telford, 209.

[73] Telford, 207-212.

[74] Clare Stoughton-Harris, 'Treatment of 20th-Century Rubberized Multimedia Costume: Conservation of a Mary Quant Raincoat (ca. 1967)', in *Saving the Twentieth Century: The Conservation of Modern Materials, Proceedings of a Conference, Symposium '91, Ottawa, Canada, 15-20 September 1991*, ed. David W. Grattan, 213-222 (Ottawa: CCI, 1993).

again used but no reasons were given as to why this choice had been made. The treatment was also outlined in *Chemical Principles of Textile Conservation* and here it was noted that: 'Viscose rayon and cellulose acetate fibres are weaker when wet. The coat was therefore supported on nylon mesh screens during the wet cleaning process, to reduce the risk of mechanical damage that might arise by the increased weight of the coat in the washing and rinsing solutions.'[75]

The physical properties causing the reduced wet strength of viscose rayon and cellulose acetate could be a reason why fewer wet cleaning treatments have been carried out but there is still little known about the effects of wet cleaning or detergents on synthetic fibres. These physical properties will be discussed further in Chapter 2.

The treatment of a cellulose acetate Dior costume was detailed in Frances Hartog's *Costume Cleaning Conundrums* article for the V&A Journal in 2008. This provided a thorough record of the object's history and condition as well as information on the treatment undertaken. Issues with cleaning the semi-synthetic fabric were considered and 'the decision was made to wash the jacket, bodice and skirt, in the knowledge there could be colour loss and not knowing what level of soil release would be achieved.'[76] While wet cleaning tests were carried out using a non-ionic wash solution and a chelating agent was added to the wash bath to 'maximise cleaning efficiency', no detergent name was included and no information given to why a non-ionic detergent was selected.[77]

These case studies draw attention to the limited information available to conservators wanting to wet cleaning synthetic fibres. The treatments emphasize the potential issues of reduced tensile strength or dye loss to the fibres but provide little evidence on the rationale behind decisions made in relation to the wet cleaning process and detergent choice. In these cases it appears that the detergent, Synperonic N, was selected due to it being the main surfactant used within the UK at that time (as previously mentioned in 1.3.1.), rather than it being identified as the most appropriate for use on synthetic fibres. This lack of information highlights the need for further research in this area.

1.5. Conclusion

The review of literature has served to provide a subject for this investigation by identify a gap in the conservation research. It was evident, from the limited sources available, that the conservation of synthetic fibres was an area currently under-researched. Further reading

[75] Tímár-Balázsy and Eastop, 139-143.
[76] Hartog, online.
[77] Hartog, online.

highlighted the lack of existing material on wet cleaning synthetics, an area chosen for this research for the reasons outlined below:

The increase of twentieth-century objects into textile collections are likely to result in more interventive treatments being carried out, generating a need for further research in this area. While a number of conservation practices could benefit from more investigation it was considered useful to examine the process of wet cleaning as it is expected that modern textile objects, like historical textiles, will collect dirt and soiling and therefore require cleaning. The decision to wet clean a textile is dependent on an understanding of how the fibres and soiling will react when introduced to wash solutions. Conservators have built up scientific knowledge relating to natural fibres but with little research having been conducted on synthetics, in particular detergency choice, it is more difficult to make an informed decision on the most appropriate materials and washing method to use.

This review has not only influenced the chosen research topic but it has aided the selection of experimental methods, to include fibre, soiling and detergent type, that are outlined in Chapter 3.

The following chapter will now examine the synthetic fibre properties that affect how the fibres react in water.

Chapter 2 - Properties of Synthetic Fibres

2.1. Introduction

This chapter examines the chemical and physical properties of synthetic fibres, focusing on those characteristics which influence the moisture absorption, tensile properties and wet strength, an issue noted in a number of case studies reviewed in Chapter 2.[78,79] Although the concern of reduced tensile strength was only recorded for semi-synthetic fibres it was thought beneficial to compare and contrast semi-synthetic and synthetic fibres as both types would undergo wet cleaning tests during this investigation.

A brief summary of the manufacturing process of man-made fibres will also be provided to show how it is responsible for differences between semi-synthetic and synthetic fibre properties. Factors affecting soiling and staining of these fibres will also be considered.

The fibres examined in this chapter (see Table 1) are the ones that have been selected to use as test specimens during this investigation and were influenced by the review of literature. The reasons for this selection are detailed in Chapter 3, section 3.3.1.

2.2. Overview of Fibre Properties

A fibre's properties 'are determined by the molecular structure and the molecular organisation.'[80] They are responsible for the variations between fibres and while there are many different properties of fibres only those relevant to moisture absorption and tensile strength will be examined. Properties considered relevant to how the fibres will respond to various soiling, stains or detergents will also be included.

Tímár-Balázsy and Eastop describe how understanding these fibre properties can be extremely beneficial to the conservation of an object, and this 'explains the emphasis on investigating materials prior to conservation.'[81] The properties of semi-synthetic and synthetic fibres can provide information on how different fibres may respond to water and wet cleaning treatments, for example the effects of wet cleaning on viscose rayon fabrics investigated by Charlotte Gamper for her Masters dissertation, 2012.[82]

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[78] Telford, 207-212.

[79] Tímár-Balázsy and Eastop, 139-143.

[80] A.F. Richards, 'Nylon Fibres,' in *Synthetic Fibres: Nylon, Polyester, Acrylic, Polyolefin,* ed. by J. E. McIntyre, 45 (Cambridge: Woodhead Publishing Ltd in association with The Textile Institute, 2005).

[81] Tímár-Balázsy and Eastop, 143.

[82] Gamper.

Conservation literature has already revealed that viscose rayon has poor wet strength while the tenacity of polyester fibres remains unaffected.[83,84,85] Being aware of the effects of water on synthetic fibres is essential to the selection of conservation treatments.

By evaluating the fibre properties some evidence for how and why the fibres may react differently to water and soil removal can be identified, helping to build on exisitng wet cleaning research in relation to synthetic fibres.

2.3. Chemical Structure of Fibres - Polymerisation

All textiles are made up of long, linear molecules called polymers, meaning *many units.* The polymers are composed of small individual units or monomers and the process in which monomers join to become polymers is known as polymerisation.[86]

Man-made fibres fall into two categories of polymer. A *homopolymer* is a polymer made up of one kind of monomer, such as the cellobiose unit in cellulose acetate, hereafter referred to as acetate. When two or more monomers are present, as with polyester for example, it is referred to as a heteropolymer or copolymer.[87] Table 1 gives the polymer type for each of the four fabrics used in this investigation.

When comparing the structure of fibres on a molecular level some similarities can be made between natural and synthetic fibres. Both cellulosic and semi-synthetic (regenerated) fibres are homopolymers, due to the fact that they share the same raw material (cellulose). It also appears that some synthetic fibres are more comparable to proteinaceous, with both types falling under the copolymer heading.

This information can provide some indication of how man-made fibres may react similarly to natural fibre types during wet cleaning. While it is not fully understood whether the polymer category could affect the fibre properties it is possible that man-made fibres will follow similar patterns to natural fibres in terms of detergent types (e.g. an anionic may by more efficient on semi-synthetics as they work well with cellulosic fibres while a non-ionic could produce better results on synthetic polymers in a similar way to protein fibres.

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[83] Cook.

[84] Tímár-Balázsy, 'Drying Behaviour of Fibres', 663.

[85] Capucine Korenberg, 'How Fast do Polyester Fabrics Age in the Museum Environment?', *V&A Conservation Journal,* Summer 2003, Issue 44. http://www.vam.ac.uk/content/journals/conservation-journal/issue-44/how-fast-do-polyester-fabrics-age-in-the-museum-environment/ (accessed 03 April 2013).

[86] E. P. G. Gohl and L. D. Vilensky, *Textile Science: An Explanation of Fibre Properties* (Melbourne: Langman Cheshire Pty Ltd., 1981), 1.

[87] Tímár-Balázsy and Eastop, 3.

2.4. Fibre Production of Synthetics

Synthetic and semi-synthetic fibres are 'made by extrusion of fibre-forming substances in liquid form […] through fine holes in a spinneret.'[88] The substances are made using a raw material, which differs between fibre types. Semi-synthetics are naturally occurring and often use cotton linter or wood pulp while synthetics are built from simple chemicals or monomers.[89] The International Organisation for Standardization (ISO) defined true synthetics 'as fibres manufactured from polymers built up from chemical elements or compounds, in contrast to fibres made from naturally occurring fibre-forming polymers.'[90]

Once extruded the fine liquid polymers are hardened to form filaments, a process known as *spinning*. For man-made fibres there are three main spinning processes: *wet spinning*, *dry spinning* and *melt spinning*. In wet spinning the fibre-forming material is dissolved in a solvent and the liquid polymers extruded into an aqueous bath where the filaments coagulate and harden as a result of chemical or physical change. Dry (solvent) spinning also dissolves the polymers in solvent but it is then extruded into a stream of hot air which evaporates the solvent leaving behind solid filaments. For melt spinning the fibre-forming substance is made liquid by heating, until it melts. The molten liquid is extruded from the spinneret and hardens as it cools.[91,92]

A summary of the different raw materials and spinning type used in the production of each of the selected fibres, along with the polymer type is outlined on Table 1 to show the differences between semi-synthetic and synthetic fibres.

[88] Cook, xvii.

[89] Tímár-Balázsy and Eastop, 57-59.

[90] J.E. McIntyre, ed. *Synthetic Fibres: Nylon, Polyester, Acrylic, Polyolefin,* (Cambridge: Woodhead Publishing Ltd in association with The Textile Institute, 2005), 1.

[91] Tímár-Balázsy and Eastop, 56.

[92] Hatch, 100.

Table 1 - Summary of chemical properties and fibre process

Fibre Type	Fibre	Polymer Type[93]	Raw Material[94]	Process[95]
Semi-synthetic	Cellulose Acetate	Homopolymer	Wood pulp or cotton linters	Dry Spinning (wet spinning is also used but less often)
	Viscose Rayon	Homopolymer	Wood pulp or cotton linters	Wet Spinning
Synthetic	Nylon	Copolymer	Chemical compound/Monomer	Melt Spinning
	Polyester	Copolymer	Chemical compound/Monomer	Melt Spinning

After extrusion the filaments need to be stretched (or drawn) to orientate the long molecules. Unlike natural fibres, synthetic fibre characteristics, such as orientation and tensile strength properties, can be controlled at this stage to produce highly orientated filaments with increased strength.[96] These properties will now be examined in more detail.

2.5. Degree of Orientation

All fibres are made up of crystalline (well-ordered) and amorphous (non-ordered) regions. The ratio of crystalline to amorphous (degree of orientation) is determined by the size and location of the polymer side groups and is responsible for a number of fibre properties, such as tensile strength and absorption.[97] The flatter the polymer chains (due to small side groups), the closer the chains can align, resulting in a highly crystalline structure. However, for semi-synthetic and synthetic fibres the orientation can be modified and controlled during the stretching process to increase the number of crystalline regions and improve the fibres strength.

The amounts of crystalline and amorphous regions differ for individual fibres and those with a larger proportion of amorphous regions are more flexible and absorbent yet weaker and less durable.[98] The degree of orientation also affects the deterioration of the fibres, as deteriorating agents can access the amorphous regions more easily that crystalline areas.

[93] Gohl and Vilensky, 4.
[94] Tímár-Balázsy and Eastop, 59.
[95] Tímár-Balázsy and Eastop, 56.
[96] Cook, xxi.
[97] Tímár-Balázsy and Eastop, 10-11.
[98] Gohl and Vilensky, 28.

2.6. Degree of Polymerisation

The degree of polymerisation (DP) is the average number of monomer units found in a polymer. Tímár-Balázsy and Eastop state that: 'Fibres with long polymer chains (high DP) are mechanically stronger than those containing predominantly shorter polymer chains (low DP).'[99] Therefore the degree of polymerisation can greatly affect the tensile strength of fibres. The DP can be reduced by age or chemical treatments, which result in a decrease in strength.

The degree of orientation and DP have been summarised in Table 2 below.

Table 2 - Summary of fibre structure and properties

Fibre Type	**Fibre**	**Degree of Polymerisation**[100]	**Degree of Orientation**[101]	**Hydroscopic Nature/ Absorption**[102]
Semi-synthetic	Cellulose Acetate	~250-300	~ 40% crystalline 60% amorphous	Most hydrophilic of the hydrophobic Slightly absorbent
	Viscose Rayon	~400	35-40% crystalline 60-65% amorphous	Hydrophilic nature Very absorbent
Synthetic	Nylon	~ 50-80	65-85% crystalline 15-35% amorphous	Hydrophobic nature Not absorbent
	Polyester	~ 115-140	65-85% crystalline 15-35% amorphous	Hydrophobic nature Not absorbent

2.7. Fibre Structure Relating to Moisture Absorption and Tensile Strength

Above is a summary of the properties considered relevant to a fibre's moisture absorption and tensile strength. The information provided will now be assessed and compared to explain how the four fibres react differently to moisture (in terms of wet cleaning) and the reasons for this.

Although all four fibres undergo similar processing methods there appear to be many variations between the properties of the four fibres. This is more evident when comparing semi-synthetic with synthetic fibres, as seen in Tables 1 and 2.

As previously mentioned the fibre properties are determined by the structure of the fibre, which in the case of man-made fibres can be modified and controlled. The higher percentage of amorphous to crystalline regions in semi-synthetic fibres results in more

[99] Tímár-Balázsy and Eastop, 11
[100] Hatch, 180-225.
[101] Gohl and Vilensky, 210-211.
[102] Gohl and Vilensky, 210-211.

flexible, stretchy and absorbent fibres. However, the orientation of semi-synthetic fibres differs from pure synthetics, which are more highly crystalline and therefore have increased tensile strength.[103] This is likely due to differences occurring during the processing stage where spinning and stretching of synthetic polymers are often to a higher extent that semi-synthetics.

The tenacity of fibres is mainly dependent on the degree of orientation but DP can also affect the fibres strength, with long polymer chains resulting in stronger fibres. However, as all man-made fibres have undergone chemical processing the polymer chains are much shorter that those of natural fibres. While this causes reduced strength in semi-synthetic fibres (which have high amorphous regions) the high crystallinity of polyester and nylon helps to increase the fibre strength.

Along with tenacity, moisture absorption is also very dependent on the degree of orientation and the less crystalline the structure the more hydrophilic (absorbent) the fibre. Cook states: 'The reduced crystallinity of the cellulose in viscose rayon renders the fibre more responsive to water-penetration.'[104] This is because the amorphous regions enable water molecules to enter the polymer chains, making it a highly absorbent fibre. Acetate does not absorb as much water as rayon, due to the presence of more crystalline regions.[105] However, it is still relatively amorphous and is weaker when wet. Both nylon and polyester are highly crystalline and therefore don't enable water molecules to enter the polymer chains in the way semi-synthetic fibres do.

The high amorphous ratio of acetate and viscose rayon influences their reduced wet strength, as identified in the review of literature.[106,107] As the water enters the polymer chains it forces them to move apart, reducing the forces of attraction (bonds) between polymers and causing the fibres to swell. Because of their high crystallinity, neither nylon nor polyester is affected in this way and minimal swelling occurs in water.[108] It should be noted that poor wet strength is an important factor to consider when wet cleaning a textile and care should be taken in supporting the object if the process is used. However, there is limited information on how much the practice of wet cleaning affects the fibres strength once dried and this is an aspect that will be assessed during this investigation.

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[103] Cook, 32.
[104] Cook, 32.
[105] Cook, 94.
[106] Hatch, 194.
[107] Tímár-Balázsy and Eastop, 142.
[108] Gohl and Vilensky, 63-115.

The amount of moisture absorbed by a fibre is also dependant on its polarity, which determines its hydroscopic nature. Many textile fibres are hydrophilic, meaning they are able to attract water molecules due to the presence of polar hydroxyl groups in the fibre's polymer chains.[109] The fact that viscose rayon is highly absorbent is due to the number of water-attracting hydroxyl groups present in the cellulose molecule. Although cotton and other cellulosic fibres have these hydroxyl groups they have more highly crystalline regions than viscose rayon, which reduce the amount of water molecules being taken up by the polymers. The high amorphous regions of viscose rayon make it easier for water to enter and remain. Many of the hydroxyl groups in cellulose acetate are replaced with non-polar acetate groups. This reduces the amount of water molecules being attracted and makes it a less absorbent fibre than viscose rayon.[110] Both nylon and polyester fibres are hydrophobic, meaning they do not attract water molecules. This is due to their very high crystalline regions and reduced number of hydroxyl groups. Although nylon contains polar amide groups which are attracted to water molecules, the crystalline structure reduces water molecules bonding to the fibres.[111]

2.8. Moisture Absorption Affecting Soiling and Staining

The moisture absorption properties of fibres can affect the way they attract and respond to soils and stains. These properties are outlined below to provide information that may be beneficial to this investigation, particularly for the testing and analysis of results.

The lower moisture absorption of acetate, nylon and polyester fibres cause static electricity to develop, as they do not take up enough water molecules to disperse the build-up of it.[112] This static electricity can attract dust and dirt particles, causing these fibres to soil more quickly.[113]

While these fibres are prone to attract loose particulate soiling the reduced number of hydroxyl groups in the polymer chains prevent water-soluble stains from bonding strongly to the fibres.[114] Cook notes that the 'relatively low moisture absorption of acetate fibres renders acetate less liable to damage by staining with many substances. Fruit juices, ink, food and other water-soluble stains are easily sponged or washed out.'[115] This is also the case for nylon and polyester, although some sources state that nylon has a tendency to hold

[109] Gohl and Vilensky, 21-24.
[110] Cook, 32-94.
[111] Gohl and Vilensky, 108.
[112] Hatch, 206.
[113] Gohl and Vilensky, 24.
[114] Tímár-Balázsy and Eastop, 58.
[115] Cook, 97.

more stains due to the polar amide groups.[116] Viscose is more susceptible to staining than other man-made fibres due to its high moisture absorption and attraction to water molecules.

However, the hydrophobic nature of nylon and polyester fibres means they are much more vulnerable to attracting oily and greasy stains than semi-synthetics. The benzene rings in polyester account for this and because of their completely hydrophobic nature they attract greasy stains more easily than nylon. Furthermore the low moisture absorption makes these fabrics more difficult to wash as it is harder for the water molecules to penetrate the fibres and reach the stains.[117]

2.9. Conclusion

This Chapter has identified the properties of semi-synthetic and synthetic fibres that affect the moisture absorption and tensile strength. It has shown that the processing methods of these fibres has caused the differences between fibres and highlighted the possible conclusions that may occur from the wet cleaning tests undertaken for this investigation. The effects of these properties on how the fibres attract soils and stains have also been examined.

The methodology and testing rationale now follows.

[116] Hatch, 206.
[117] Hatch, 218.

Chapter 3 - Methodology and Testing

3.1. Introduction

This section introduces the experimental design used to assess the effects of conservation wet cleaning, with different detergents, on four man-made fibres. These effects will be measured by examining changes to visual and physical properties of the test specimens, focusing in particular on their tensile strength and the amount of soil removed following standardised wet cleaning tests.

This chapter provides an outline of the rationale and decisions behind each component, followed by a detailed account of the preparation of test specimens and the procedures used throughout the research, to include the wet cleaning process and methods of assessment.

Following the review of literature a number of research questions were devised to help focus the research, help develop the project aims and aid analysis of results. The research questions are listed below and will be referred to throughout this dissertation research:

- Can synthetic fibres be cleaned using water and/or detergent?
- Are there any detrimental effects to the fibres?
- Which detergent(s) is most suitable for each synthetic fibre?
- Which detergent(s) is more effective at soil removal?

3.2. Rationale

From completing a literature review it was clear that very little information was available on the wet cleaning of synthetic fibres. Where these treatments were documented no guidelines were available on the most suitable detergent for individual man-made fibres or synthetics in general.

It was therefore considered beneficial to investigate the effects of different wet cleaning solutions on the fibres' strength as well as their ability to remove soiling, as both of these factors would be considered prior to conservation wet cleaning treatments on history textiles.

Soil removal was examined with the aim of comparing the efficiency of a number of different wash solutions and to identify whether certain detergents were more suitable for particular synthetic fibres.

Tensile strength testing was completed to help detect whether the wet cleaning process affected the fibres tensile properties. It also helped highlight any differences between wash solutions containing different types of wet cleaning detergent.

3.3. Test Material Selection

3.3.1. Types of Fabric

Ferreira's paper into objects composed of manufactured fibres helped to identify which fibres may be the most beneficial to test. During her research a questionnaire was sent to textile conservators and curators across the United States of America to gather information relating to manufactured-fibre objects present in collections and to identify which were more in need of conservation treatments and/or further research. The responses showed that viscose rayon then acetate was most frequently encountered for conservation, followed equally by nylon and polyester. It was also identified that all manufactured-fibres required a similar need for conservation.[118]

Four different man-made fibres were selected for this dissertation research. These included two semi-synthetic fibres: cellulose acetate and viscose rayon and two synthetic fibres: nylon and polyester. A list of the chosen fibres can be seen in Table 3 below and fabric samples are in Appendix 1. The fibre choice was based on the findings from Ferreira's research and is considered representative of man-made fabrics as it offers a range of semi- and synthetic fibres. These four fabrics were also the most accessible at the time of this research.

Table 3 - Selected fabrics

Polymer Class	**Fibre Type (Generic Name)[119]**	**Chemical Name[120,121]**
Semi-synthetic	Acetate	Secondary Cellulose Acetate
	Viscose Rayon	Regenerated Cellulose
Synthetic	Nylon	Polyamide
	Polyester	Polyethylene terephthalate (PET)

[118] Ferreira, 13.

[119] British Standard, *Textiles – Man-Made Fibres – Generic Names BS ISO 2076:2010* (London:British Standard Institute, 2010), 7.

[120] Cook.

[121] McIntyre.

While it may have been possible to use 'sacrificial' historical objects, it was decided that testing new fabrics would provide more controlled results and would limit variables from past use or previous cleaning. Undyed, plain weave fabrics (for the four selected fibres) were chosen for consistency, to reduce factors that may affect the test results such as differences in weave structure and the presence of dyes or mordents from coloured or patterned fabrics (a variable which Gamper found problematic when interrupting results for her dissertation research).[122]

3.3.2. Types of Staining

Past research, such as Lewis and Eastop, Tinkham and Kerr, and Reponen, previously used commercially produced standard soiled test fabrics.[123,124,125] However, it was not suitable for this research project due to the limited range of pre-soiled synthetic fabrics available. For this reason it was decided to artificially stain the test specimens by hand. This method would also help the tests to be reproducible, as the composition of the soiling would be known.

A review of conservation literature and textile industry sources offered information on different categories of staining, which helped to narrow down the selection of soils and stains.[126,127,128] The information gained from textile science text books, as outlined in Chapter 2, also provided details on how different types of stains are attracted to different fibre types. After a number of experimental wet cleaning tests were undertaken, in which a range of stains were compared, three types of stain were deemed appropriate for this research.

The three stains were chosen as they represented different categories of soiling and had the potential to be removed or reduced by one or all of the different wash solutions. Pre-testing eliminated certain stains that bonded permanently to the test fabrics and would therefore not be removed or achieve any results. The three stains are outlined in Table 4.

[122] Gamper.
[123] Lewis and Eastop, 73-89.
[124] Tinkham and Kerr, 47-58.
[125] Reponen, 321-326.
[126] Ballard, 89-101.
[127] Tímár-Balázsy and Eastop, 157-174.
[128] EMPA, online.

Table 4 - Selected stains

Number	Type of Stain	Category of Soiling	Additional Information
1	Orange Juice	Acidic, fruit stain	Smooth not from concentrate 100% orange juice (non-diluted)
2	Olive Oil and Soot	Greasy and particulate	Olive oil mixed with soot produced from burning paper, wood, smokeless fuel and coal (0.25g soot in 10ml oil, w/v)
3	Coffee	Water soluble and colour stain	Rich roast freeze dried instant fair trade coffee (5g coffee in 100ml boiled tap water, w/v)

It was also considered beneficial to age the stained samples prior to testing. This would help fix the fresh stains more securely to the fibres and make the process more realistic in terms of conservation wet cleaning.

3.3.3. Types of Wash Solution

The wash solutions were based on a review of related literature and the researchers own experiences. Water and two detergent types were selected to enable a comparison of conservation wet cleaning solutions and to investigate if certain solutions work better for different stains and fibre types.

Water was selected as it is the most polar solvent available and dissolves a wide range of soils and stains. It is also a common solvent for conservation as it is readily available, cheap and less aggressive to textile fibres than detergents.[129]

An anionic and a non-ionic detergent were also chosen to compare their effectiveness of soil removal and to identify whether different detergent solutions can cause more damage to the fibres tensile strength than others or water alone. Orvus WA® paste belongs to a common class of anionic detergent and as one of the most researched anionic surfactants available, it was selected for its frequency of use, most often on cellulosic based fibres.[130,131] The non-ionic detergent Dehypon LS45® was chosen due to its availability and general all-round effectiveness. While non-ionic detergents are usually thought to work best on proteinaceous fibres Dehypon LS45® is considered effective at soil removal for most fibre types.[132,133]

[129] Tímár-Balázsy and Eastop, 194.
[130] Ballard, 92.
[131] Lewis and Eastop, 73.
[132] Lewis and Eastop, 73.
[133] Fields et al, 64.

3.4. Test Specimen Preparation

Two types of test specimens were produced with the aim of testing both the tensile strength and the soil removal of the different fibres after conservation wet cleaning. It was decided that these factors should be tested separately to help make the tests more accurate and reduce the possibility of the stains affecting the tenacity of the fabrics. Although all samples underwent the same wet cleaning tests, the preparation of specimens differed slightly. The preparation methods for both specimen types are outlined below.

3.4.1. Soil Removal Test Specimens

Each specimen was cut to an 80 x 80mm square, which allowed enough space for three different stains to be present, with minimal overlapping, but also enabled all samples to fit in the ageing oven together.

Three sets of test specimens and one control were cut for each fibre type, with each set consisting of four specimens to ensure more accurate results. Pinking shears were used to limit the amount of fibres that might fray and become loose during the testing.

3.4.1.1. Method of Staining

To ensure the soiling was consistent and that all specimens received the same amount of soiling in the same location, apparatus was set up to secure a soil-filled pipette above each specimen (fig. 1). All 52 test specimens (12 to undergo wet cleaning tests and 1 control for each of the 4 fabrics) were stained consecutively to guarantee accuracy. Each specimen contained the three stains, consisting of two pipette drops for each stain type. All 52 test specimens were soiled with stain 1 first, before stains 2 and 3 were added respectively. Figs.1 and 2 show the arrangement. Once stained, all test specimens were placed in a plastic tray and covered with melinex. They were conditioned in this way for one week at room temperature to allow the stains to dry and bond to the fibres.

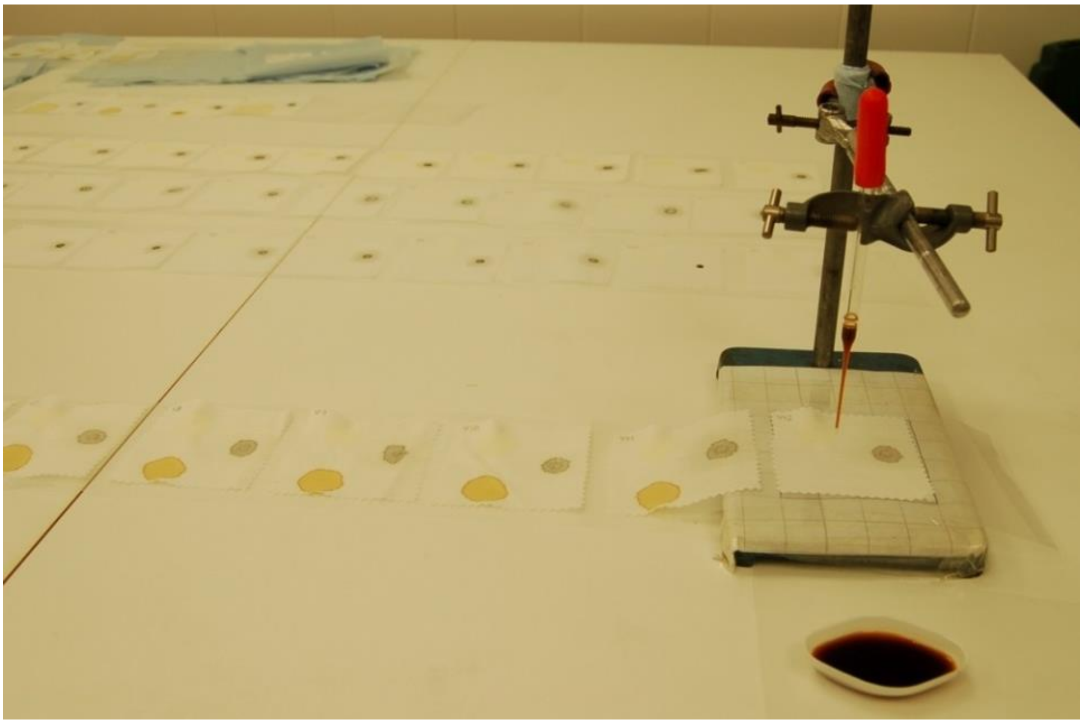

Fig. 1 - The apparatus set up to ensure accurate staining of test specimens. Stain 3 is being applied

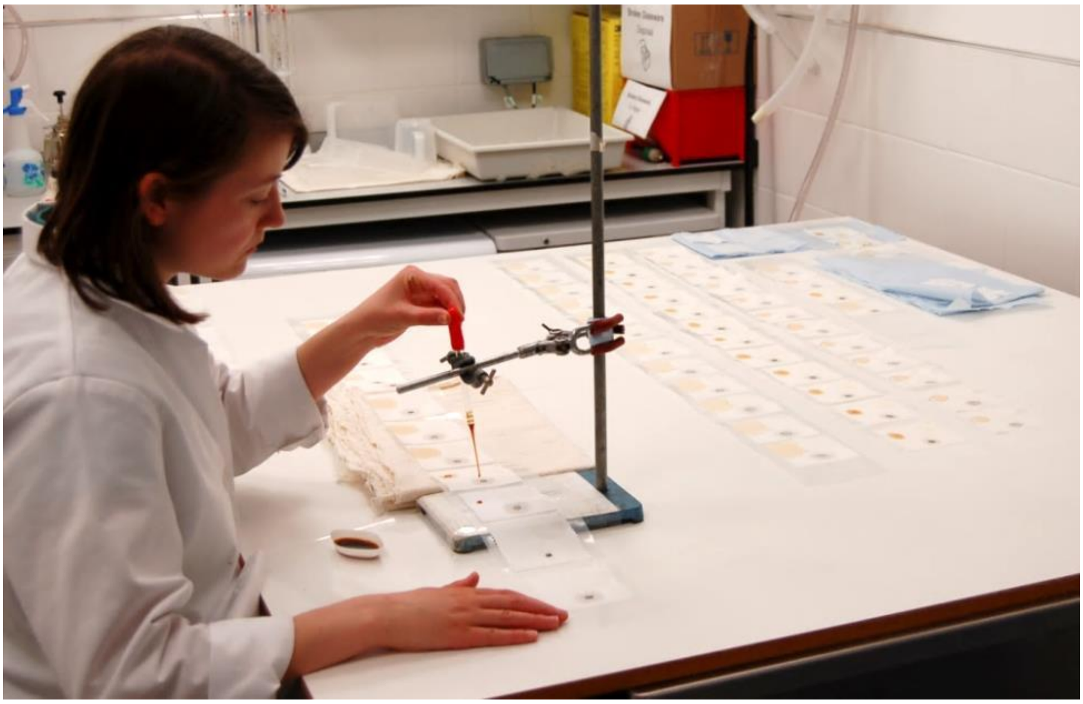

Fig. 2 - Preparing the soil removal test specimens with three different stains

3.4.1.2. Artificial Ageing

After a week of conditioning at room temperature all test specimens were placed in the thermostatically-controlled oven to accelerate the ageing of the stains. The specimens were tied to the metal shelves with polyester thread (see fig.3) and left in the oven at 70^{o}c for exactly seven days. Only temperature was used to age the specimens, as this process was to help fix the stains rather than to create artificially historic textile samples. The seven day time frame was gauged from pre-testing and was considered lengthy enough to sufficiently fix the stains while still enabling them to be removed (to some degree) during the washing process.

Fig. 3 - Soil removal test specimens in the oven to begin artificial ageing

3.4.2. Tensile Strength Test Specimens

The test specimens used for testing tensile strength were prepared differently to the soil removal test specimens. The British Standard *Textiles - Tensile Properties of Fabrics* (BS EN ISO 13934-1:1999) was used as a guide and helped to control the preparation of test samples under the strip method.[134] While most criteria were completed in accordance with BS EN ISO 13934-1:1999 some aspects (for example specimen size) were altered as it was deemed more appropriate for this research. These changes are explained in the following paragraphs.

[134] British Standard, *Textiles - Tensile Properties of Fabrics, Part 1: Determination of Maximum Force and Elongation at Maximum Force Using the Strip Method BS EN ISO 13934-1:1999* (London: British Standard Institute, 1999), 5-6.

Four sets of test specimens and one control were cut for each fabric type, with each set consisting of five test specimens (as advised in BS 13934-1:1999) in the warp direction only. As the test specimens were required to determine changes between detergents rather than assess the overall quality of the fabric (as for manufacturing purposes) it was decided that testing specimens from the weft threads were not needed for this research. While no test specimen contained the same warps, the samples were cut across the fabric and contained the same wefts.

Each test specimen was cut to half the size of that outlined in the British Standard to give a dimension of 25mm width (excluding fringe) and a gauge length of 100mm. In accordance to BS 13934-1:1999 an extra 25mm was added to each end to allow enough fabric to be gripped in the jaws of the testing machine. A fringe of approximately 5mm was also added to each side of the long edge. Due to the requirement of fringed side edges only the ends were pinked for these samples. Each test specimen had a final dimension of 35mm width x 150mm length as shown in fig. 4. All samples were prepared in exactly the same manner.

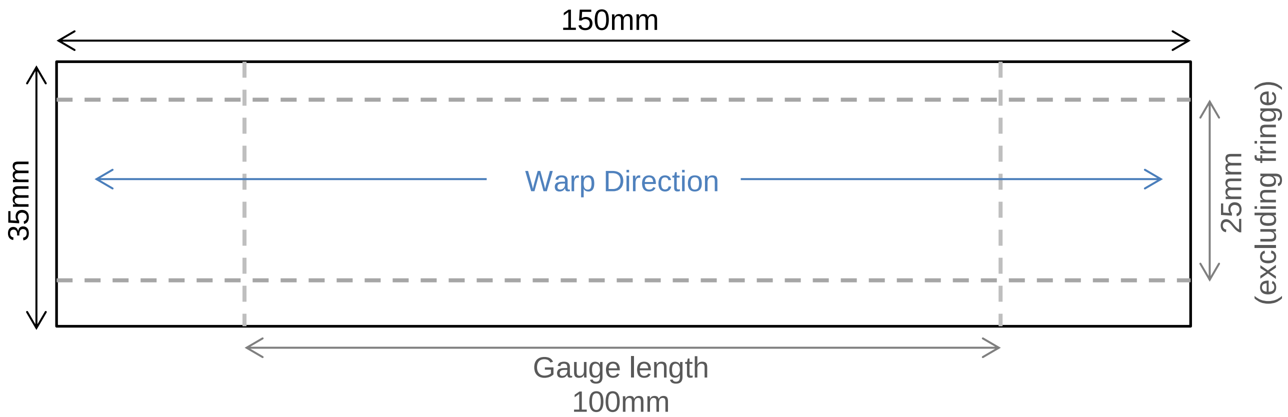

Fig. 4 - Tensile Strength Test Specimen (Strip Method)

3.5. Test Variables

To help keep the tests as precise as possible variables were kept to a minimum. All fabrics were new, undyed and plain weave. However, it was not possible to order all from the same supplier and only limited information was available about the fabric type, date and production method.

While all testing was done within a set time frame, the environment (temperature and relative humidity) was unable to be controlled and as a result the tests were undertaken within an uncontrolled environment. However, all conditions were recorded.

The test variables for this research were:

- Untreated specimens (or controls)
- Treated specimens for soil removal testing using
  - Soft tap water
  - Anionic detergent
  - Non-Ionic detergent
- Treated specimens for tensile strength testing using
  - Soft tap water
  - Anionic detergent
  - Non-Ionic detergent

3.6. Tests Stages and Sets

The wet cleaning tests were completed in two stages. Stage one tested the soil removal test specimens and stage two the tensile strength test specimens. While these tests were undertaken separately they all followed a standardised wet cleaning procedure.

The soil removal test specimens had three sets of four specimens for each chosen fabric. One unwashed and untested control sample for each fibre type was used as a comparison after wet cleaning. Table 5 shows a breakdown of the different stages and sets and the corresponding treatment.

The tensile strength test specimens consisted of four sets of five specimens for each chosen fabric. A set of untreated specimens (Set 5) was required for each fibre type to compare the tenacity of the unwashed fabric to that of the treated specimens. Sets 6 - 8 were treated specimens. Each fabric also had one unwashed and untested control.

The stages and sets for all test specimens are outlined in Table 5.

Table 5 - Stages and sets for all test specimens

Testing Stage	Treatment (Set Number)	Fabric Type (Test Number)	Number of Specimens
Stage 1 Soil Removal Specimens	1 Soft Water	a Acetate	4
		b Rayon	4
		c Nylon	4
		d Polyester	4
	2 Anionic	a Acetate	4
		b Rayon	4
		c Nylon	4
		d Polyester	4
	3 Non-Ionic	a Acetate	4
		b Rayon	4
		c Nylon	4
		d Polyester	4
Stage 2 Tensile Strength Testing Specimens	5 Untreated	a Acetate	5
		b Rayon	5
		c Nylon	5
		d Polyester	5
	6 Soft Water	a Acetate	5
		b Rayon	5
		c Nylon	5
		d Polyester	5
	7 Anionic	a Acetate	5
		b Rayon	5
		c Nylon	5
		d Polyester	5
	8 Non-Ionic	a Acetate	5
		b Rayon	5
		c Nylon	5
		d Polyester	5

3.7. Conservation Wet Cleaning Method

A standardised wet cleaning procedure was devised for all tests and can be seen in Table 6. This treatment was based on a number of previous wet cleaning research projects.[135,136] However, the cycle was lengthened to more accurately replicate the common wet cleaning treatment for historical textiles as taught at the *Centre for Textile Conservation and Technical Art History (CTCTAH)*.

The wash solution was either soft tap water[137] or a detergent solution of water mixed with an anionic or a non-ionic detergent depending on the specimen set being tested. Each bath consisted of the four or five test specimens from one set. Each set was washed together to keep variations between specimens to a minimum. The wash solution for each specimen set was 500ml, which provided sufficient water coverage of all specimens. Only one wash solution was added for each bath due to the minimal amount of particulate soiling present.

A Ramer® sponge, made from polyvinyl alcohol (PVA) foam, was used for the sponging stage. This type of sponge was favoured over the natural sponges more regularly used in conservation wet cleaning as it could be cut in half and its pour size was more consistent (which reduced the sponge affecting the foaming qualities of the detergent).

Table 6 - Standardised wet cleaning treatment

Wet Cleaning Stage	**Cycle**	**Time (minutes)**
Wash Solution (Soft tap water, Anionic detergent or Non-Ionic detergent)	Soak front	15
	Sponge front	15
	Soak back	15
	Sponge back	15
Soft Water Rinses (Water changed after each 5 minute rinse)	Rinse back	5
	Rinse back	5
	Rinse front	5
	Rinse front	5
Deionised Water Rinse	Soak	10
Drying	Placed in blotter	5
	Total:	1hr 35mins

[135] Reponen, 321-326.
[136] Lewis and Eastop, 73-89.
[137] Sourced from the soft water geographical region of Glasgow.

An example of a more detailed wet cleaning record can be seen in Appendix 2. Fig. 5 below shows an example of the soaking and sponging stage of the wet cleaning cycle.

Fig. 5 - Soak (left) and sponge (right) in wet cleaning cycle on soiled test specimens (Test2b)

3.7.1. Wash Solution Preparation

To keep the testing consistent, a standard concentration of five times their critical micelle concentration (cmc) in soft water was used for both the anionic and non-ionic detergent wash solutions. Wash solution calculations are given in Appendix 2. To ensure accuracy, one batch of each detergent was made up and used for all testing.

While temperature plays a role in the solubility of detergents it differs for both detergent types, with anionic often requiring temperatures above 40^{o}c and non-ionic dissolving readily in cold water.[138] It was therefore decided that testing would be carried out at room temperature to lessen the effects of water temperature on the test specimens, which could affect the amount of soiling released or the fibres tensile strength. It was also considered more representative of general wet cleaning practice, where often the water temperature cannot be controlled. The average temperature of wash baths is also provided in Appendix 2.

[138] Tímár-Balázsy and Eastop, 202-207.

3.8. Methods of Evaluation

Four methods of evaluation were selected. Three different methods were chosen to help evaluate the soil removal test specimens. Tensile strength testing was used to evaluate the fabrics' strength of untreated and treated test specimens. Each method is outlined in more detail below.

3.8.1. Visual Analysis

The soiled test specimens were visually examined before and after wet cleaning tests. Photographs were taken to help with comparison and a stereomicroscope was used to detect any changes to the fabrics surface. Tested samples were compared to the controls.

3.8.2. Colour Readings

Colour readings were taken before and after artificial ageing as well as after wet cleaning. This was to examine the result of ageing and compare the effectiveness of soil removal. A Minolta Chroma meter CR-210 was used to measure the total colour change for each stain (fig. 6).

Fig. 6 - Measuring colour readings of a stains test specimen using the Chroma meter

Each of the three stains for all four fibre types were recorded to identify whether the wash solutions had affected the stains differently. Templates were produced to ensure that the same area of staining was being tested (fig. 7). All readings were measured with the specimen placed on top of a white blotting paper square to reduce the colour readings being affected by the surface below, to keep testing consistent.

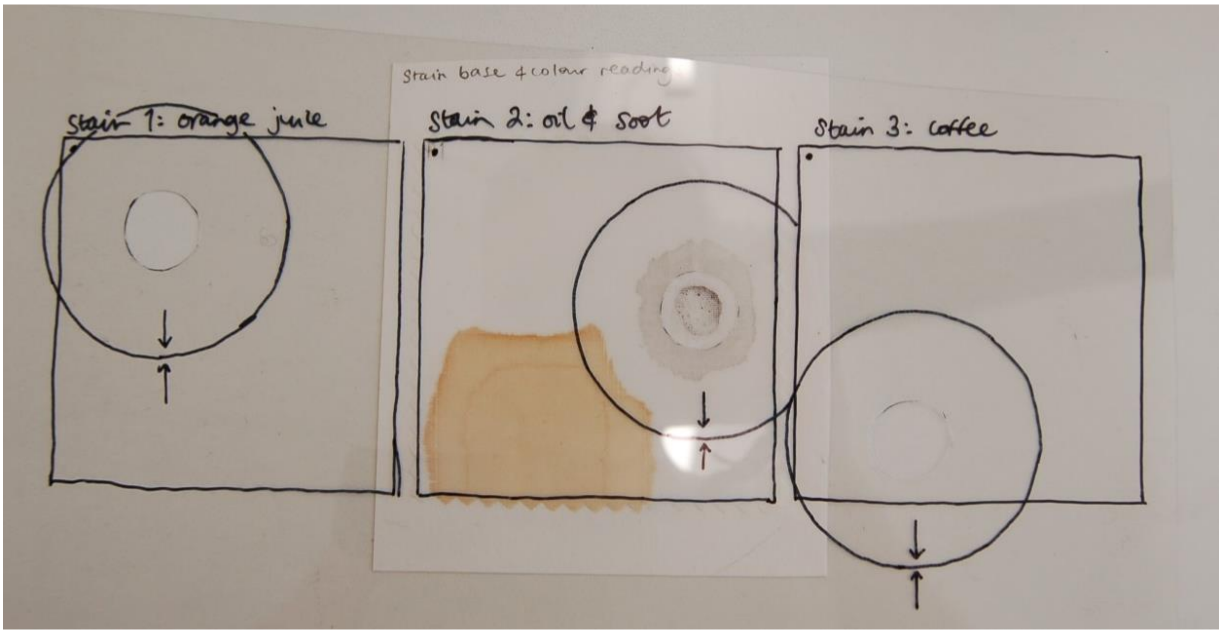

Fig. 7 - Templates for the three different stains

The L*a*b* colour space system (known as CIELAB) was used to measure lightness (L*) and chromaticity (a* and b*), which includes both hue and saturation. The a* value indicates the red (+a*) and green (-a*) chromaticity, while the b* value denotes the yellow (+b*) and blue (-b*). The higher the L* value the lighter the colour and as the a* and b* values increase or decrease from 0 the saturation also increases (fig. 8).

L*a*b* is a more precise way of measuring colour than visual analysis because each colour reading is given as a numerical value, which allows for even the smallest differences to be recognised and recorded.[139] Four measurements were taken for each fabric and treatment to ensure the results were more precise. A mean (average) value as well as the standard deviation[140] for all readings was recorded and used to produce a number of graphs, which are outlined in Chapter 4.

[139] Christine Maurhoff, ‘Commercial Spot Removal Products: Conservation’s Friend or Foe?’, MA Dissertation, Textile Conservation Centre, University of Southampton, 2008.
[140] Standard deviation is the variation from the mean, shown as error bars on histograms (see 4.3.2.).

Fig. 8 - Two chromaticity diagrams showing lightness, hue and saturation depicted as a three-dimensional diagram (left)[141] and a spherical CIELAB diagram (right).[142]

3.8.3. Weave Density

Weave density was used to identify any dimensional changes that occurred to the test specimens after wet cleaning. It was measured by counting the number of warps and wefts within a 10mm square and was undertaken on the control and each set of test specimens. A template was also used to improve accuracy and consistency.

3.8.4. Tensile Strength Testing

After undergoing the wet cleaning tests all tensile strength test specimens (including the controls and unwashed sets) were conditioned in a humidity chamber for 72 hours, as stipulated in the British Standard 13934-1:1999.[143] Although the environment was unable to be controlled the temperature and relative humidity (RH) were monitored and ranged between 23.3 - 25.5^{o}c in temperature and 35.5 - 43.5% RH.

All tensile strength test specimens were tested in one sitting to reduce any effect from changes in temperature and RH.

[141] Gustaf Svensson, 'Discolouration of Albumen Powder' http://2.bp.blogspot.com/_iefPDdrTUGY/TK0Kr9Bw2lI/AAAAAAAAAlM/5jFKX1k9DMQ/s1600/LabSys.jpg (accessed 10 July 2013).

[142] Sign & Digital Graphics, 'Optimizing Ink Density Part 2', http://sdgmag.com/sites/sdgmag.com/files/images/07_CIELAB.jpg (accessed 10 July 2013).

[143] BS 13934-1:1999, 5.

Testing was carried out using an Instron® 5544 electromechanical testing system (a single column, table-top load frame - fig. 9) and Bluehill® software.[144]

The machine measures the tensile properties of textile fabrics using the strip method as outlined in 3.4.1. An even load is applied to the test specimen to determine the maximum force required to break the specimen. The test specimen is mounted between two jaws, which are set to the required gauge length. For these tests the extension speed was set to 100mm per minute in accordance to BS 13934-1:1999.

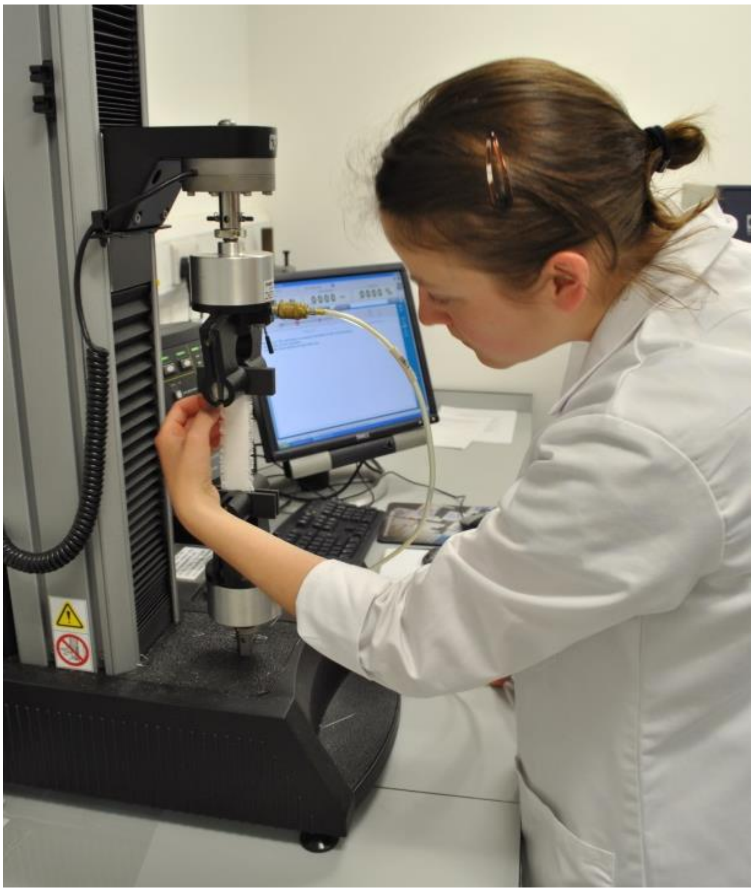

Fig. 9 - Mounting a test specimen between the Instron machines two jaws.

3.9. Conclusion

This chapter has outlined the test procedures undertaken to complete investigation into the effects of wet cleaning and conservation detergents on soiled synthetic test specimens. Both textile science literature and past conservation research projects have provided guidance for the structure and procedures involved in this research methodology.

The results gained from this investigation will now be analysed and discussed.

[144] Instron, 'Series 5500 Load Frames Including Series 5540, 5560, 5580 Reference Manual – Equipment', http://www.instron.co.uk/wa/library/default.aspx (accessed 24 June 2013).

Chapter 4 - Analysis and Discussion

4.1. Introduction

This chapter examines and evaluates the findings from the standardised wet cleaning tests. Both soil removal and tensile strength will be analysed, using the methods of assessment described in 3.8. Results from the three wash solutions will then be compared, using visual and statistical analysis to gauge the effectiveness of their cleaning properties and to identify any detrimental effects to the fibres tensile strength.

Following on from the research questions outlined in Chapter 3, a number of hypotheses were proposed for the wet cleaning tests, relating to soil removal and tensile strength. These predictions are based on the evidence identified from the conservation literature and textile science text books evaluated throughout Chapters 1 and 2. The analysis of results will attempt to prove or reject the hypotheses outlined below:

i. The wet cleaning tests will affect the tensile strength of semi-synthetic fibres more than synthetics because of their higher percentage of amorphous regions

ii. Viscose rayon will retain more water-soluble stains after wet cleaning than acetate as a result of the higher number of hydroxyl groups

iii. Stain 3 (oil and soot) will be harder to remove from polyester and nylon than the other two stains due to their hydrophobic nature resulting in attraction to oily stains

iv. Orvus WA® paste will remove more soiling from the semi-synthetic fibres while Dehypon LS45® will be more effective on synthetics, based on their comparisons to natural fibres

4.2. Statistical Analysis

Statistical analysis was completed to determine the differences between wet cleaning treatments on soil removal and tensile strength. The Student's *t*-test was used to calculate the probability of two sets of data being significantly different. Colour readings and tensile strength tests were analysed using this method and the results are given in 4.3. and 4.5. Further explanation and tables of data can be found in Appendix 5.

Standard deviation shows the variation from the mean and is used to indicate how precise the results are.[145] The lower the standard deviation the closer the results are to the mean

[145] Billie J. Collier and Helen H. Epps, *Textile Testing and Analysis* (London: Prentice Hall International (UK) Ltd, 1999), 50.

and the more precise the data. It is given as error bars on the graphs presented in this chapter.

4.3. Analysis of Soil Removal Test Specimens

4.3.1. Findings from Visual Analysis

The soil removal test specimens were visually examined before and after wet cleaning to identify the effects of artificial ageing on the three stains and to assess the amount of soiling removed from each fibre type during the three different wet cleaning treatments. These were compared to the untreated controls, which helped to highlight differences in the stains after cleaning. The visual findings from all treatments and fibres are presented in Table 7 below. The results have been divided into three criteria, to assess whether the stains were removed, reduced or unaffected by the wet cleaning tests. An explanation for the three criteria is provided in fig. 10, which shows an example of test specimens before and after wet cleaning. This is followed by a brief outline of visual conclusions for each fabric group.

Table 7 - Visual analysis of soil removal after wet cleaning tests

		Acetate			**Viscose Rayon**			**Nylon**			**Polyester**		
Stain	**Sample**	a	b	c	a	b	c	a	b	c	a	b	c
1 orange juice	AT 1			**X**			**X**			**X**			**X**
	AT 2			**X**			**X**			**X**			**X**
	AT 3			**X**			**X**			**X**			**X**
2 oil & soot	AT 1	**X**			**X**			**X**			**X**	**X**	
	AT 2	**X**			**X**			**X**			**X**	**X**	
	AT 3	**X**			**X**			**X**	**X**			**X**	
3 coffee	AT 1		**X**	**X**		**X**			**X**			**X**	
	AT 2			**X**		**X**				**X**			**X**
	AT 3			**X**		**X**			**X**				**X**

After Treatment 1 (AT 1) = Water, AT 2 = Anionic detergent, AT 3 = Non-ionic detergent

a = Unaltered, b = Reduced, c = Removed (see fig. x for reference)

Where a cross appears in two boxes it means the stain is between two criteria e.g. Unaltered and Reduced = slightly changed from original but not significantly enough to be reduced.

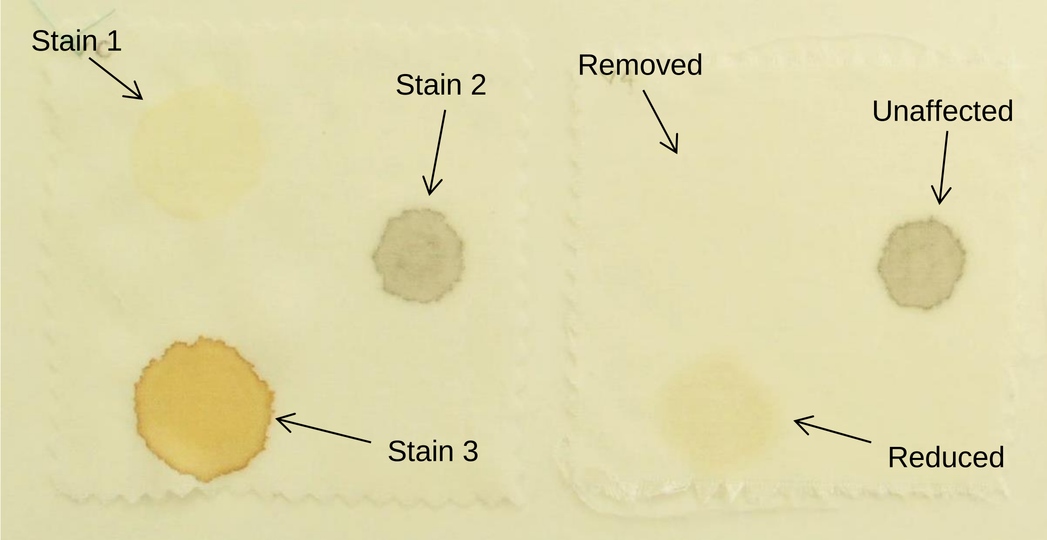

Fig. 10 - An example of before (left) and after treatment AT 1 (right) for viscose rayon defining unaffected, reduced and removed stains.

4.3.1.1. Cellulose Acetate

Both stain 1 (orange juice) and 3 (coffee) became visibly darker after artificial ageing. Stain 2 (oil & soot) did not visually change during the ageing process.

Stain 1 appeared to be removed by all wet cleaning treatments (fig. 11).

Stain 2 remained present on all test specimens. However, more soot particulates were visible on specimens cleaned with water and particles appeared to have been transferred to other areas of the sample during wet cleaning (most likely caused during sponging). Both detergents look to have reduced stain 2 but the samples all appeared slightly greasy.

Stain 3 was reduced on all test specimens, although both detergents appear to have removed more of the stain than the water.

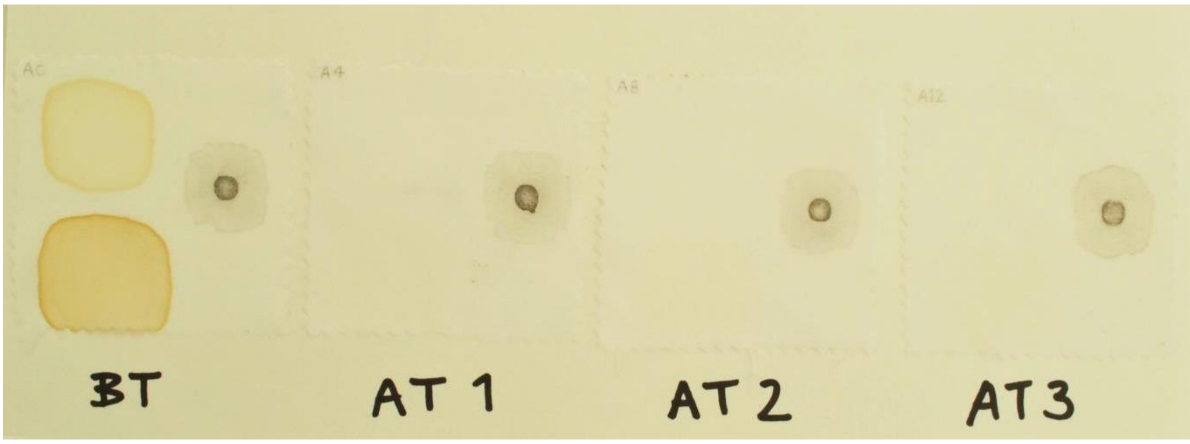

Fig. 11 - Examples of before and after treatments for acetate

4.3.1.2. Viscose Rayon

While stain 1 and 3 became darker after ageing they did not change as significantly as the other three fibre types.

Stain 1 appeared removed by all wet cleaning treatments.

Stain 2 looked less defined after cleaning but the colour was unaffected.

Stain 3 was reduced after all wet cleaning treatments, with the stain appearing fainter.

The most visually noticeable feature after wet cleaning was that all test specimens had reduced in size, an issue also observed by Telford when wet cleaning a viscose rayon kimono.[146] This will be explained further in 4.4. The test specimens were also the most visibly damaged of all four fabrics, with more fraying and loose fibres present (fig. 12).

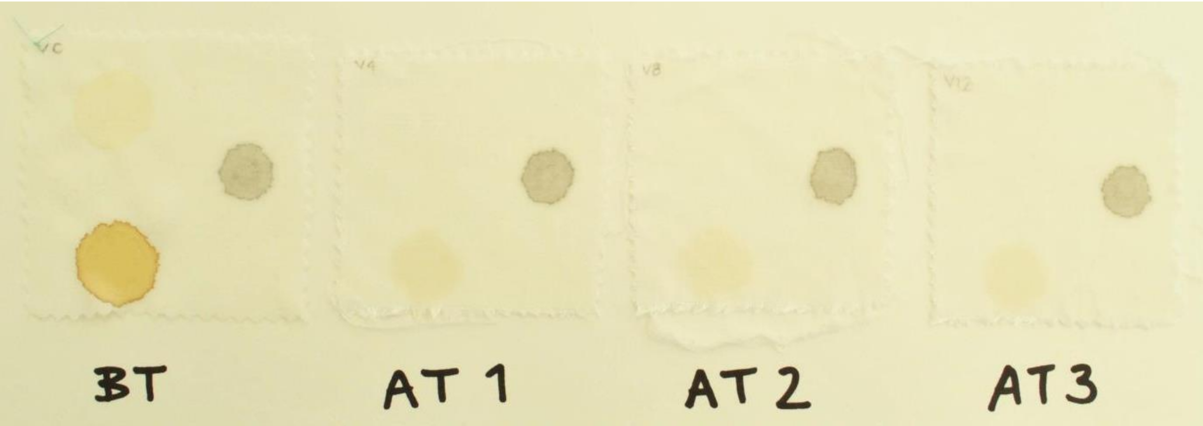

Fig. 12 - Examples of before and after treatments for viscose rayon

4.3.1.3. Nylon

Stain 1 and 3 changed the most significantly after ageing nylon than any other fibre type. Again stain 2 did not appear to have visibly altered during this process.

Stain 1 was removed and was no longer visible.

Stain 2 remained visually unaltered for test specimens cleaned in water and anionic detergent. The stain was reduced by the non-ionic detergent but was still clearly visible.

Stain 3 was still present on specimens cleaned in water and non-ionic detergent but was significantly less on those cleaned with anionic detergent (see fig. 13).

[146] Telford, 207-212.

However, all test specimens appeared greasy in areas of no staining, which is likely to have been caused by the oil wicking up the fibres while ageing. Approximately 10mm along the left side of each specimen remains un-greasy. This was the top edge that was tied to the metal shelves while hung in the ageing oven.

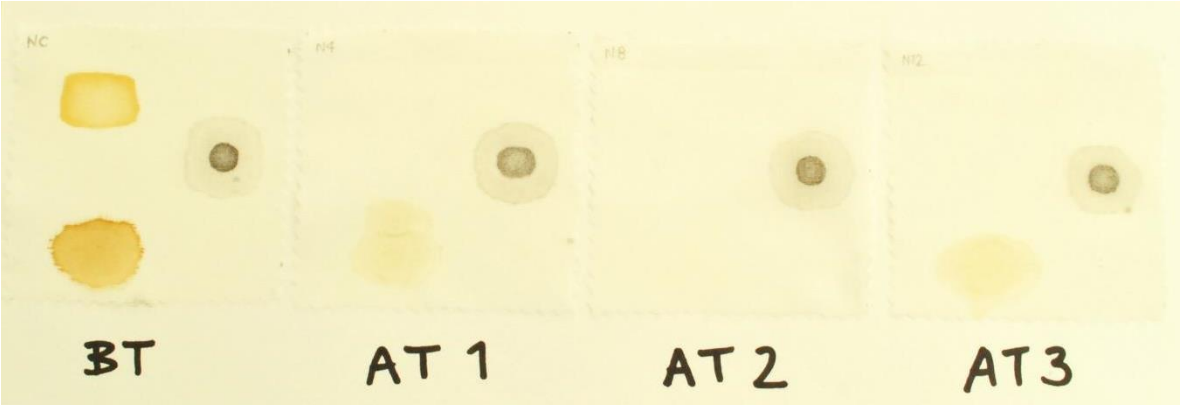

Fig. 13 - Examples of before and after treatments for nylon

4.3.1.4. Polyester

Again stain 1 and 3 became darker after ageing. Stain 2 also appeared slight darker.

Polyester was visually the most improved after all wet cleaning treatments. Both stain 1 and 3 were removed while stain 2 was reduced, for all test specimens. The anionic detergent appeared to work best at removing stain 3 and the non-ionic detergent improved the appearance of stain 2 more than the other cleaning solutions (fig. 14).

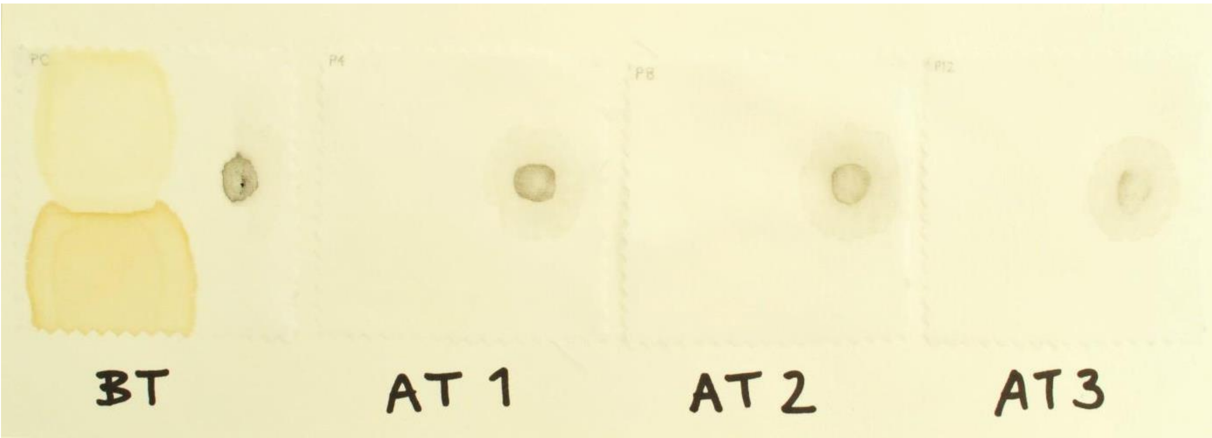

Fig. 14 - Examples of before and after treatments for polyester

4.3.2. Colour Readings

The Chroma meter CR-210 was used to measure colour change of the soiled test specimens. While many of the results were comparable to those found from visual analysis, the data helped to identify the significant differences between test specimens and revealed variations not noticeable with the naked eye. The colour reading results are compared below, using graphs and statistical analysis to aid evaluation. The graphs express the L*, a* or b* values taken from the soiled test specimens before (BT = after artificial ageing) and after wet cleaning treatments (AT 1 = Water, AT 2 = Anionic and AT 3 = Non-ionic). A small selection of graphs will be used to provide examples of common trends or to show unexpected or contradictory results. All additional colour readings and graphs are presented in Appendix 3.

4.3.2.1. Cellulose Acetate

The colour reading figures showed that both stain 1 and 3 had become lighter (see fig. 15 for L* values) and less saturated (a* and b*) after all three wet cleaning treatments, while stain 2 remained unchanged. This confirmed the findings from visual analysis.

The large standard deviation bars for stain 2 showed that the results were more varied than the other stains but that they were not significantly different from each other. This was verified by the student's *t*-test, which proved no treatment had worked at removing stain 2. The test also identified that while all after treatments for stain 1 were statistically significantly different than the untreated test specimens, they all removed the stain by similar amounts. Stain 3 showed a significant lightening on all fabrics but the detergent wash solutions were more effective at removing soiling than water by itself (fig. 15). The graphs showing a* and b* values, and statistics for these findings are all found in Appendix 3 and 5.

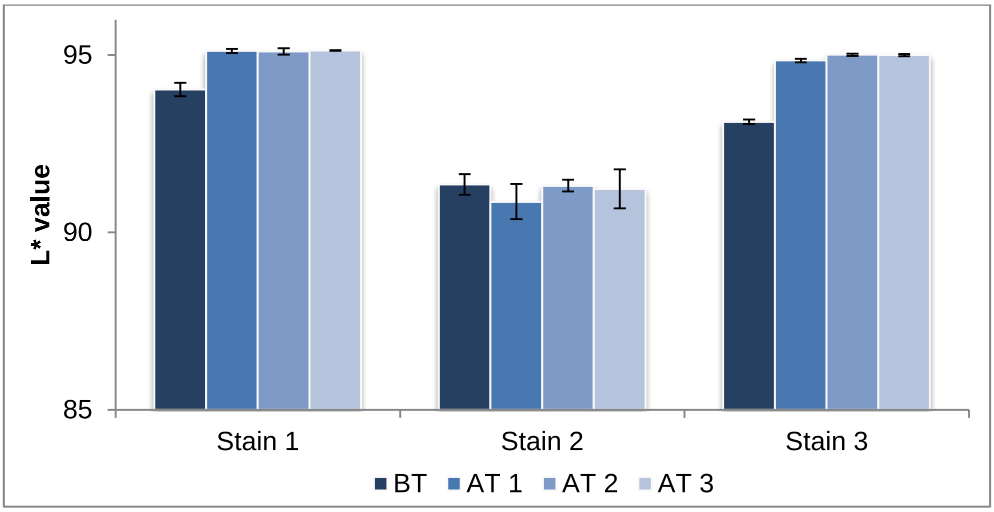

Fig. 15 - L* values showing before and after treatments for acetate

4.3.2.2. Viscose Rayon

The data from the colour readings was slightly conflicting with visual analysis. The L* values for stain 1 decreased slightly after treatment, meaning the stain had become darker (fig. 12 shows this was not the case). However, the numerical values only differed by a maximum of 0.08%, taking into account the standard deviation. The a* and b* values also showed a greater difference from before and after and it was decided that these results were more meaningful than the L* values due to the original paleness of this stain. The b* values can be seen in fig. 16, which shows the yellow axis has become less saturated for all after treatments.

From examining the figures stain 2 was found to be darker and more saturated after all treatments, which was not evident when compared to the visual finding. All after treatments show similar results and differ significantly to the untreated specimens, meaning some difference to the stain had occurred during wet cleaning.

While the L* a* b* results for stain 3 identified the stain as being significantly lighter and less saturated (fig. 16 for saturation), the stain was not found to be completely removed by any of the treatment. When compared to the untreated specimen, it was however found to be much reduced.

The student's *t*-test confirmed most of these findings but identified that there was no significant difference between the untreated and water treated (AT 1) specimens for stain 1 and that anionic detergent (AT 2) was slightly more effective at removing stain 3 than either water or non-ionic detergent.

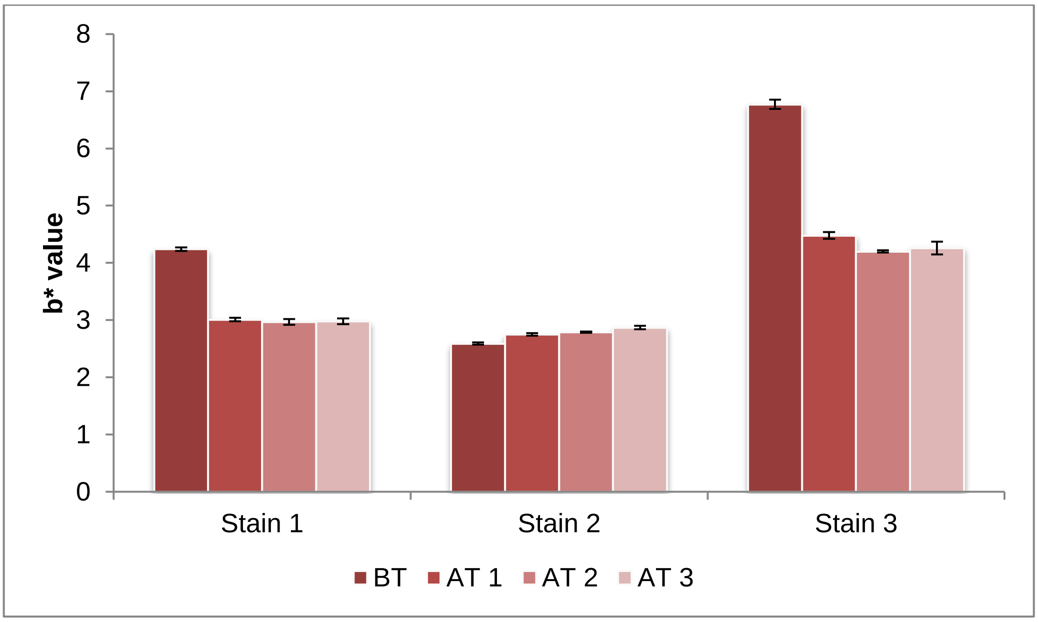

Fig. 16 - b* values showing before and after treatments for viscose rayon

4.3.2.3. Nylon

The three after treatments were found to have significantly lightened stain 1 and 3 (fig. 17) and greatly reduced the saturation. The colour reading figures, which were also confirmed by the student's *t*-test, identified that anionic detergent (AT 2) was more effective at soil removal, for both stain 1 and 3, than either water or non-ionic detergent (as seen by the taller AT 2 bar on fig. 17).

When analysing the data for stain 2 is appeared that all after treatments had intensified the stain, as with viscose rayon. However, the student's *t*-test confirmed that there was actually no statistical significant difference between the untreated test specimens and those cleaned with non-ionic detergent (AT 3), showing that this was more effective than water or anionic detergent.

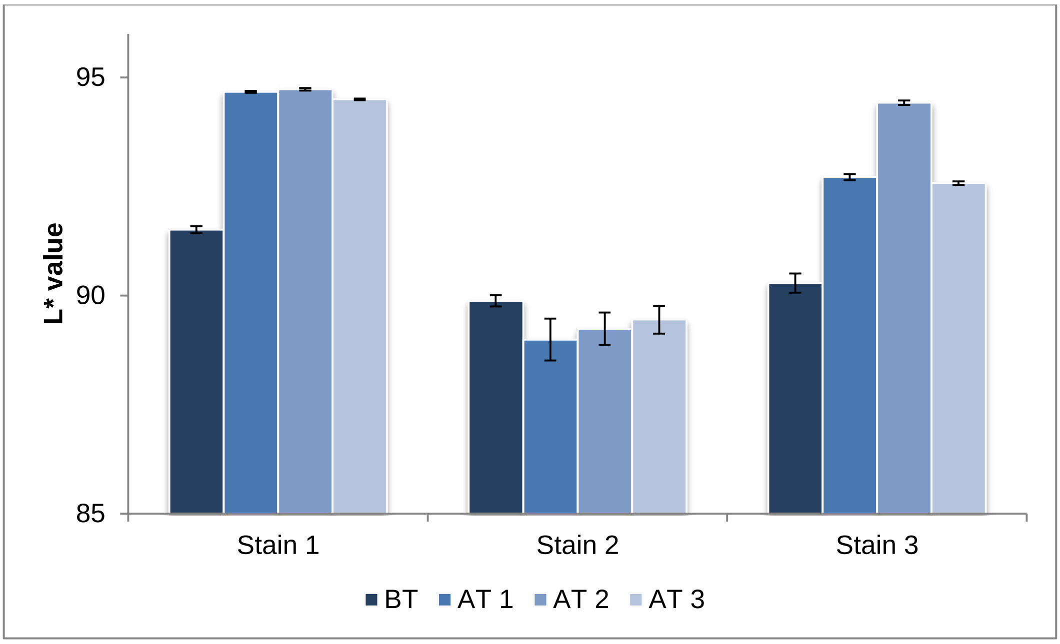

Fig. 17 - L* values showing before and after treatments for nylon

4.3.2.4. Polyester

As with acetate and nylon stain 1 and 3 on polyester was lighter and less saturated after all treatments (fig. 18). The data, confirmed by the student's *t*-test, highlighted that there was no significant difference between treatments for stain 1 but the detergent wash solutions were more effective at removing stain 3 than water.

Again stain 2 was found to have no significant difference when using the *t*-test, meaning all treatments had no effect on the stain. However, both visual analysis and the L* and a* values (fig. 18) showed that there was a slight improvement in the stain with non-ionic detergent.

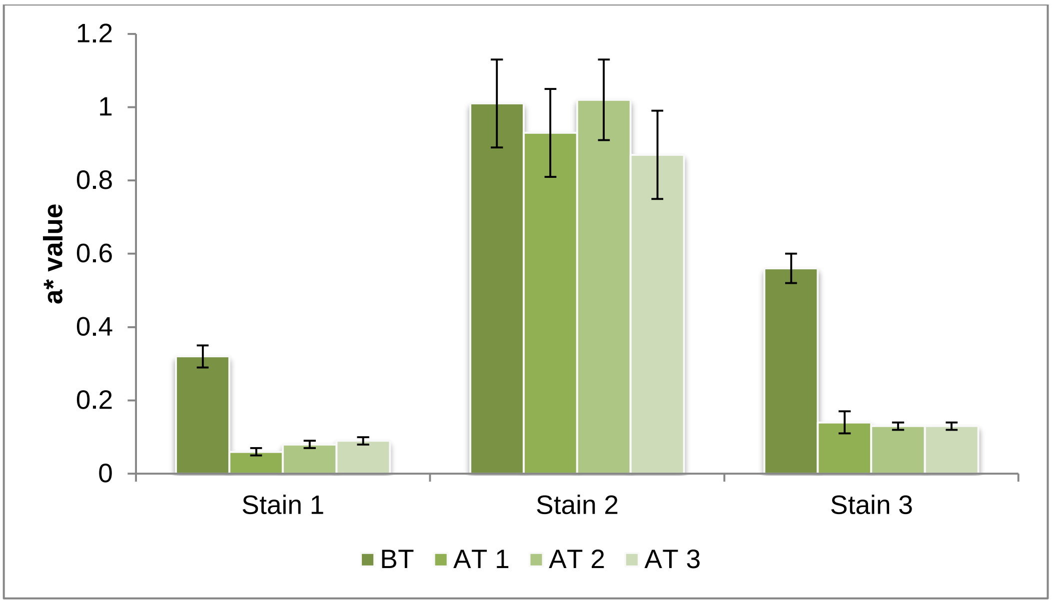

Fig. 18 - a* values showing before and after treatments for polyester

4.3.3. Discussion and Comparison of Findings for Soil Removal Test Specimens

The findings for both visual analysis and colour reading measurements have been outlined above for each fibre type. This section will discuss and compare the visual and numerical data, with the aim of identifying which detergent is most effective for which stain or synthetic fibre.

From examining the soil removal results it was found that both visual and numerical data was needed to fully analyse the test specimens. Visual examination identified a number of interesting results, which was often confirmed by the colour readings and statistical analysis. However, the student's *t*-test was not always able to identify changes that were visible from inspecting the test specimens. Therefore it was deemed beneficial to use visual analysis in conjunction with statistical analysis.

Visual examination has shown that all wet cleaning treatments removed stain 1 from all four fibre types. While the colour reading results for acetate, nylon and polyester confirmed this, the graph below (fig.19) displays no real difference between treatments for viscose rayon, as previously mentioned in 4.3.2.2.

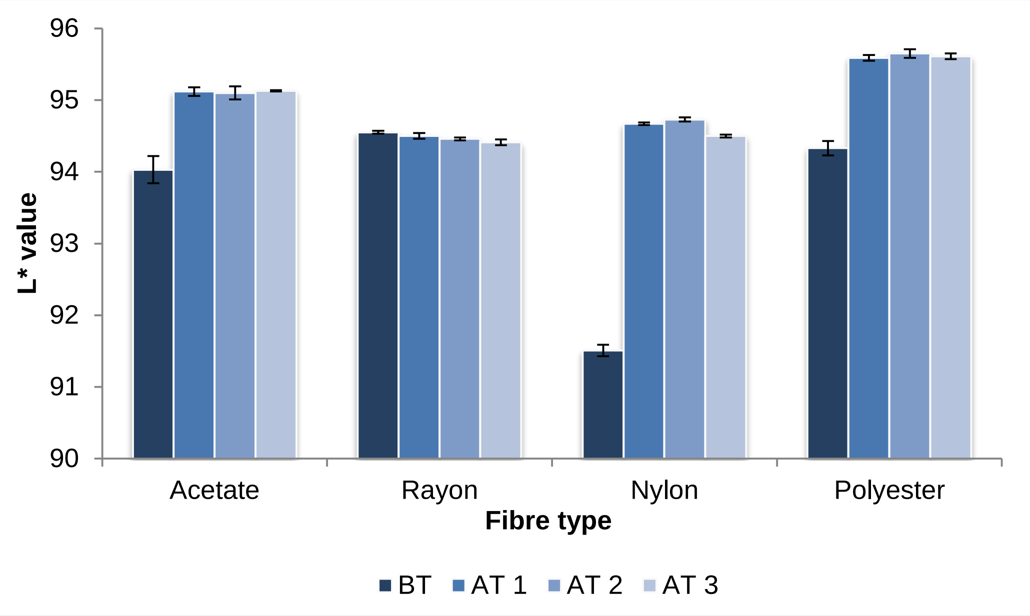

Fig. 19 - Comparison of L* values before and after treatment for stain 1

The fact that stain 1 has been removed from all fibre types suggested that this stain was less firmly bonded to the fibres. The water-soluble nature of the orange juice stain is likely to be a reason for this and may explain why there were mixed results for viscose rayon due to its high affiliation with water molecules. As explained in Chapter 2, the low moisture content of acetate, nylon and polyester has prevented the stain from entering the polymer chains, enabling it to be removed easily during the washing process. While it has been noted that nylon can hold stains more readily, due to the polar amide groups, it was not the case for stain 1.[147]

Stain 2 altered the least during wet cleaning and the only visible difference was found on polyester fabric when cleaned with non-ionic detergent solution. Although the student's *t*-test identified differences between before and after treatments for acetate and nylon the stain remained firmly bonded to the fibres. It was expected that stain 2 would be more difficult to remove, in particular from the hydrophobic polyester fibres, due to the mix of soiling (oil and soot particles) and the stain's oily nature. However, the results showed polyester to be the most improved, although this was only when washed using non-ionic detergent.

Stain 2 also posed problems during the preparation of test specimens as the soot particulates were not consistently pipetted onto the fibres. This is a variable that would need to be reduced for future testing. The inconsistencies produced during the preparation are

[147] Hatch, 206.

likely to have caused the large standard deviations for stain 2 on all fibre types, as seen in the graph - fig. 20.

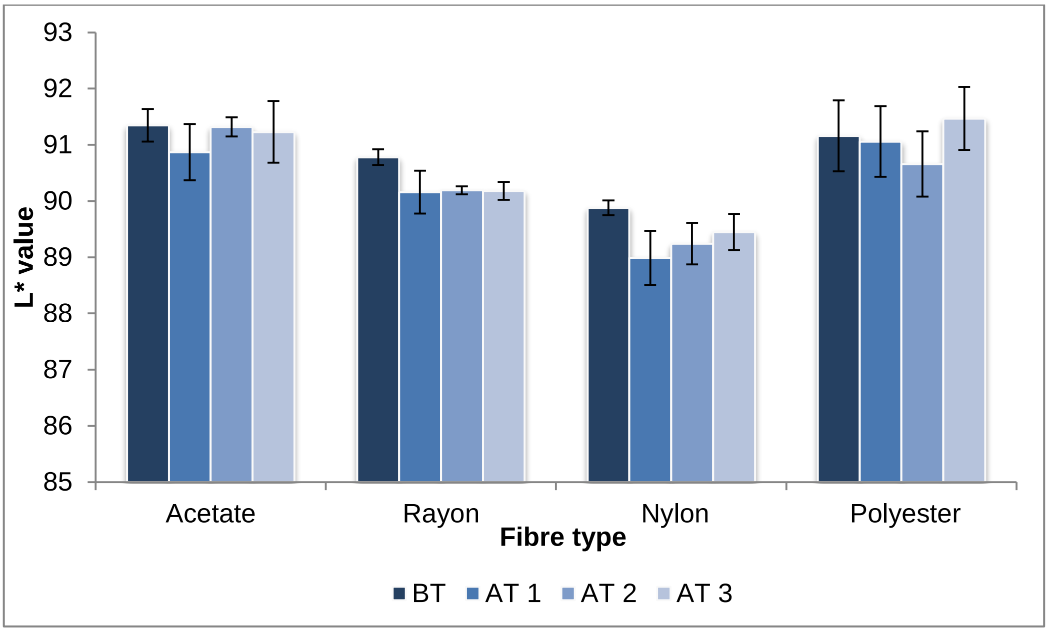

Fig. 20 - Comparison of L* values before and after treatment for stain 2

Stain 3 had mixed results for fibres and detergents. The stain was removed from polyester with all wet cleaning treatments, while the detergent wash solutions were slightly more effective than water for acetate test specimens. While stain 3 was reduced for viscose rayon and nylon fabrics it was still clearly visible, except on nylon where the anionic detergent removed the stain (fig. 21).

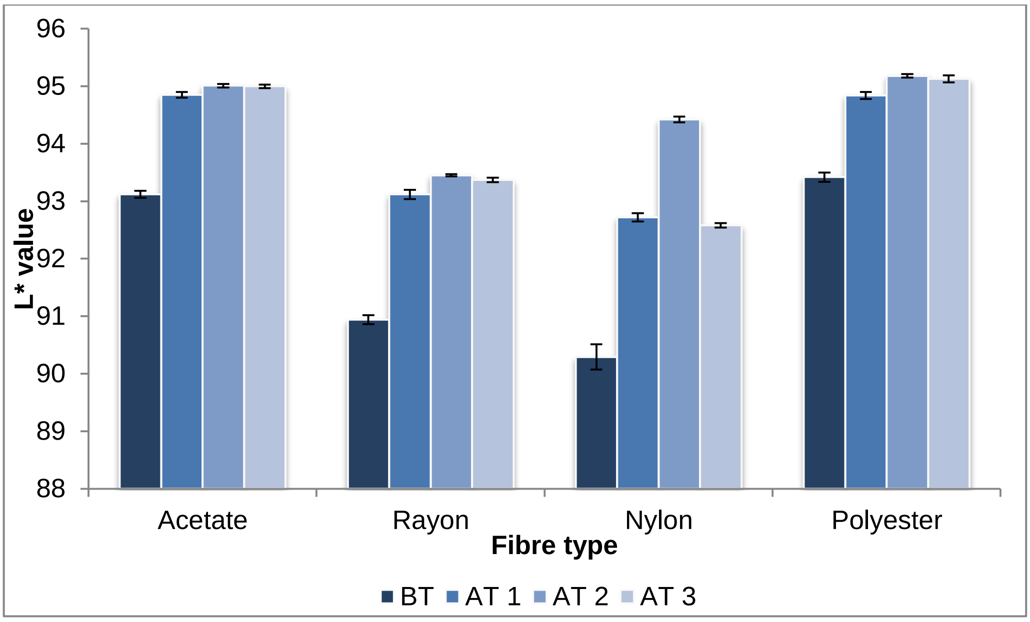

Fig. 21 - Comparison of L* values before and after treatment for stain 3

The presence of water-attracting hydroxyl and amide groups in the viscose rayon and nylon fibres is possibly a reason why the water-soluble coffee stain still remains but is not present on acetate or polyester. It was interesting to discover that the anionic detergent, Orvus WA® paste, was able to remove stain 3 from nylon but neither water nor Dehypon LS45® were effective at soil removal. A combination of soiling and fibre type is likely to be the cause for this result as Orvus WA® paste was found to be effective for stain 1 and 3 across all fibres.

Below is a summary of the detergent types that were found to be the most effective for each stain and fibre (Table 8). While a detergent type has been identified for stain 2 they did not greatly reduce the stain and other cleaning methods, for example dry or spot cleaning, may be more appropriate for textile objects.

Table 8 - Summary of the most effective detergent for tested stains and fibre types

	Stain 1	**Stain 2**	**Stain 3**
Acetate	Water or Anionic/Non-ionic	Anionic/Non-ionic	Anionic/Non-ionic
Viscose Rayon	Anionic/Non-ionic	Not removed	Anionic
Nylon	Anionic	Non-ionic	Anionic
Polyester	Water or Anionic/Non-ionic	Non-ionic	Anionic

Overall it appears that the anionic detergent was more effective at stain removal for stain 3. Anionic detergent was found to work well at removing stain 1, although non-ionic detergent (and sometimes water) was also effective. The combination of visual and numerical results show that non-ionic detergent is more effective at reducing oily and greasy stains, although stain 2 remained visible on all fibre types.

The results focusing on changes to fibre density and tensile strength after wet cleaning will now be analysed.

4.4. Fibre Density

Below is a table to show the changes in fibre density within a 10mm square, before and after wet cleaning treatments. Because all three treatments produced the same results the figures have been listed in one column. The figures given are an average of four readings.

Table 9 - Fibre density results from before and after treatment

Fibre Type		**Before Treatment**	**After Treatment**
Acetate	Warps	44	44
	Wefts	28	28
Viscose Rayon	Warps	**28.5**	**32**
	Wefts	**27**	**28**
Nylon	Warps	40	40
	Wefts	25	25
Polyester	Warps	40	40
	Wefts	24	24

No wet cleaning treatment affected the density of the weave for acetate, nylon or polyester. The structure of viscose was affected by water as all three treatments produced the same results. Both the warps and wefts contracted after wet cleaning, increasing the number per 10mm square (shown on the table in bold) and resulting in smaller test specimens. This was evident from visual analysis as the test specimens were significantly smaller, changing from an 80mm square to 75mm square (a reduction of 6.6%).

4.5. Tensile Strength Testing

Tensile strength testing measures the fabric's strength by extending the test specimen to its breaking point, recording the breaking force and elongation.[148] Elongation is the distance a fabric specimen can stretch and extend under an applied force, and is measured in millimetres (mm). Breaking force (load) is the amount of force required for a test specimen to fail and is measured in Newtons (N). These measurements are presented as a force-elongation or load-extension curve as shown in fig. 22.

[148] B. P. Saville, *Physical Testing of Textiles*, (Cambridge: Woodhead Publishing Ltd in association with The Textile Institute, 2009), 145.

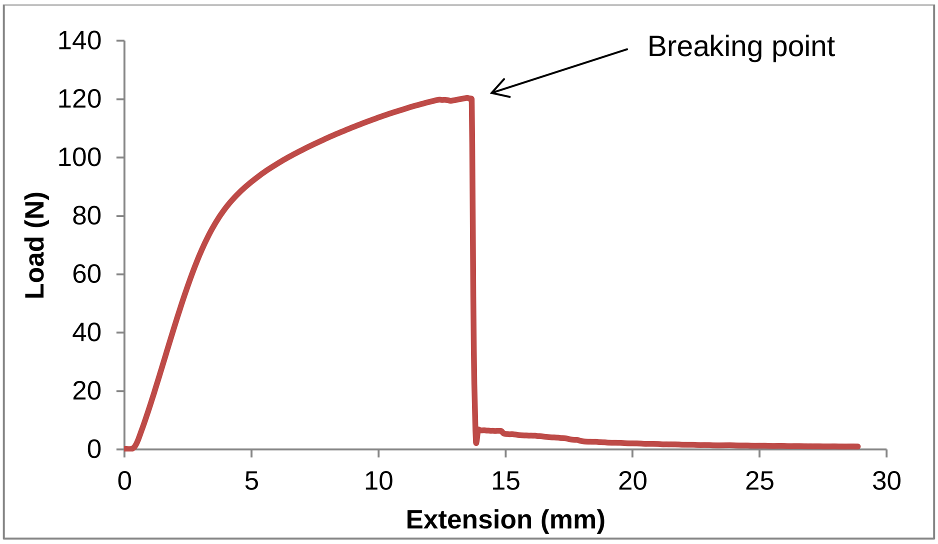

Fig. 22 - Load-extension curve for acetate before treatment

The initial curve before breaking point shows the increase in tension being applied to the specimen until it breaks.[149] The curve following failure denotes the load required to break any remaining fibres still intact. A steep drop means the majority of fibres in the test specimen break immediately and the curve continues until all fibres have failed, as seen in fig. 22.[150]

While tenacity[151] is often used to compare fibres of different thicknesses it was not deemed relevant for this research as the test specimens were being compared to each other within their fibre type.

The tensile strength results for all fibre types will be examined at the same time, using a selection of graphs and the student's *t*-test to help evaluate the finding. (All load extension graphs and statistical analysis for all fibres and treatments are provided in Appendix 4 and 5). The student's *t*-test was used to help interpret the graphs, making the results more understandable. The after treatments of all fibre types will then be compared to evaluate the effect of different wash solutions on the fibres tensile strength. Reference to the fibre properties detailed in Chapter 2 will also be made.

4.5.1. Comparison of Findings for Tensile Strength Test Specimens

The load-extension curves for acetate and viscose rayon showed more variation between untreated and treated test specimens than those of nylon or polyester, as seen in the combined graph below (fig. 23). While the fibres cannot be compared fully to each other,

[149] Tímár-Balázsy and Eastop, 13.
[150] Gamper, 75.
[151] Measures specific stress at breaking point relating to fibre density, Tímár-Balázsy and Eastop, 13.

due to different fibre thicknesses, the graph provides an example of their differing tensile strengths and gives an idea of whether the treatments have or have not affected this. The load-extension curves for all fibres can be seen in Appendix 4.

The graph clearly shows that some changes have occurred to the semi-synthetic fibres while the synthetics appear unaffected by the wet cleaning process. The higher percentage of amorphous regions in the acetate and viscose rayon fibres are probably the reason for this. Damage from swelling may have occurred during the washing process and it is possible that water molecules were retained in the polymer chains, affecting their tensile strength. The synthetics show a steep drop after breaking point. This is likely due to their higher crystalline regions, which cause the fibres to be stronger yet less elastic. As this drop was present for both before and after treatments it was not considered a result of the washing process.

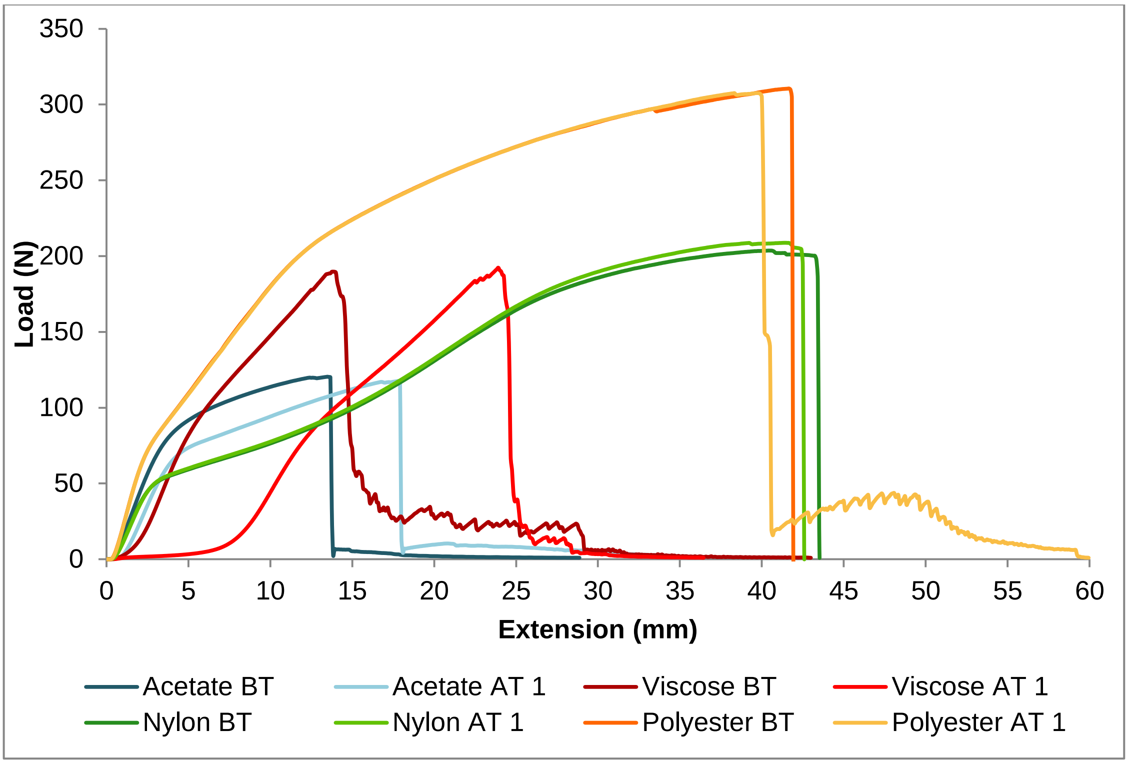

Fig. 23 - Load-extension curves for all fibres, showing before and after treatments

The findings from the load-extension curves were analysed and combined in Table 10, which shows a summary of the tensile strength testing results. The effects of each wash solution on the fibres strength are present.

Table 10 - Summary of the effects of wet cleaning on tensile strength

	AT 1 - Water		AT 2 - Anionic		AT 3 - Non-ionic	
	Load	Extension	Load	Extension	Load	Extension
Acetate	No affect	Increased	Increased	Increased	Increased	Increased
Viscose Rayon	No affect	Increased	Reduced	Increased	No affect	Increased
Nylon	No affect	Increased	No affect	No affect	No affect	Increased
Polyester	No affect	No affect	No affect	No affect	No affect	No affect

The table above shows that wet cleaning with water had no effect on the load at failure for any of the four fibre types. The student's t-test also identified that there was no significant difference to the load between the untreated specimens (BT) and those treated with water. Neither anionic nor non-ionic detergent affected the load at failure for nylon or polyester, and viscose rayon was not affected by non-ionic detergent. However, both detergent wash solutions increased the breaking strength for acetate, as seen in Table 10 and fig. 24. A reduction in load occurred when viscose rayon test specimens were washed in anionic solution, highlighting the potential for anionics to cause more damage to viscose rayon fibres than either water or non-ionic detergent.

This information is also presented in the graph below (fig. 24).

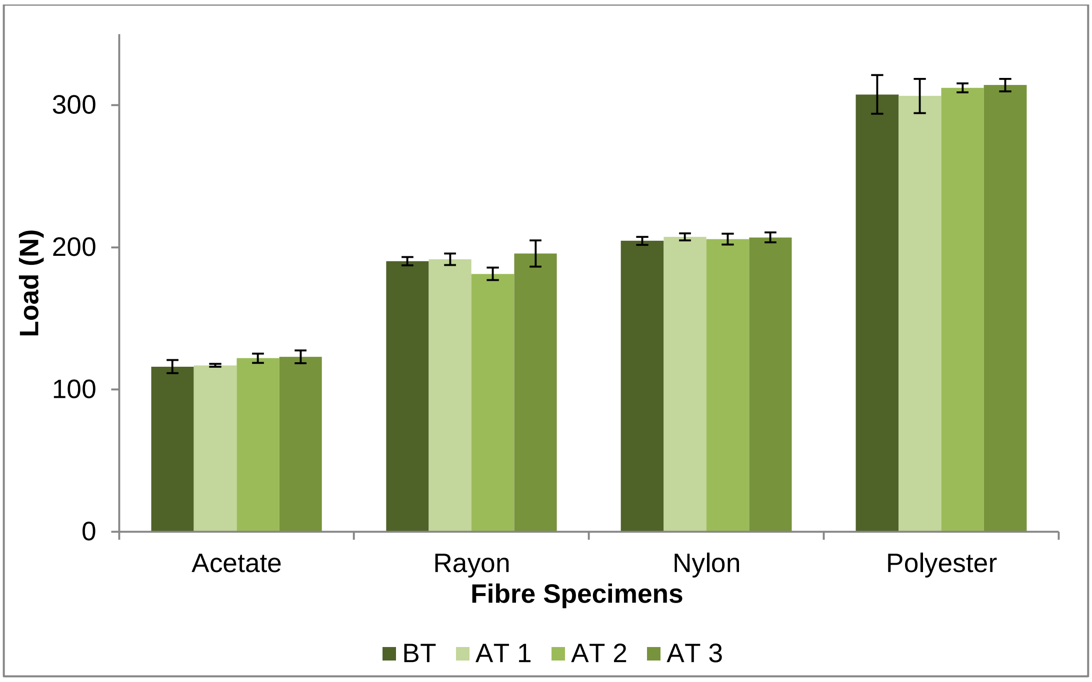

Fig. 24 - Load at failure before and after treatment for all fibres

All three treatments for viscose rayon and acetate have significantly greater extension than the untreated specimens, meaning the wet cleaning treatments (or the introduction of water) have affected the fibres strength (fig. 25). The extension at failure for nylon test specimens was also increase when cleaned with water or non-ionic detergent but anionic detergent was not found to have an effect. None of the treatments affected polyester, due to its completely hydrophobic nature.

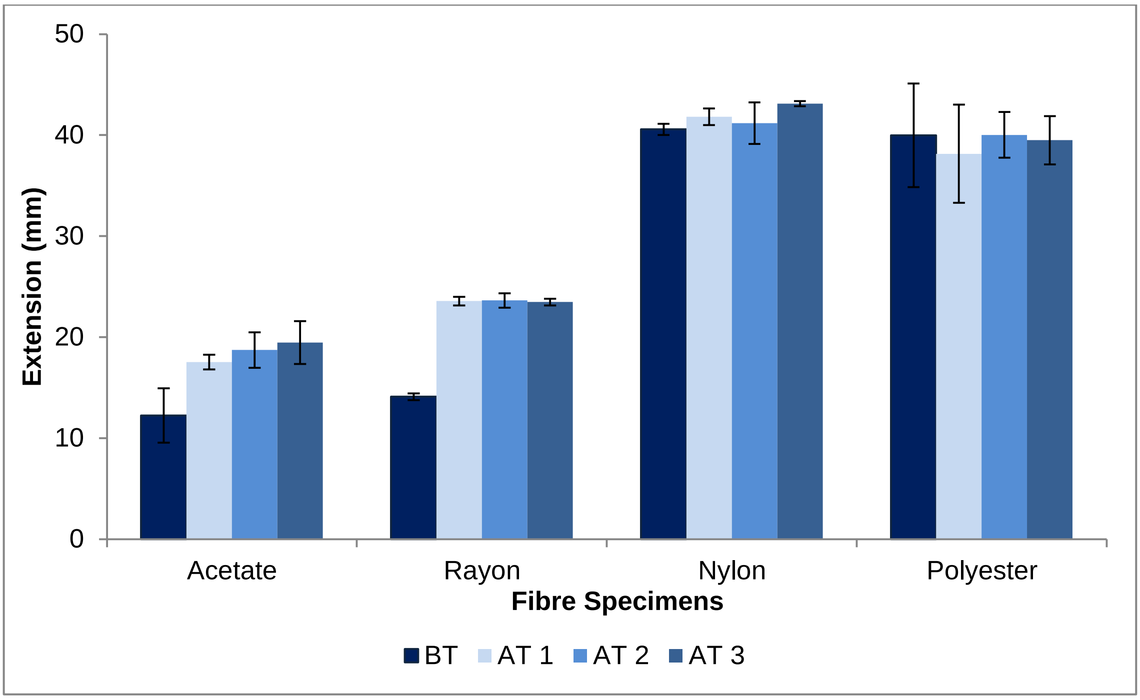

Fig. 25 - Extension at failure before and after treatment for all fibres

4.6. Conclusion

This chapter has examined the results from visual and numerical analysis to determine the consequences of wet cleaning synthetic fibres with different wash solutions. Soil removal and tensile strength were evaluated to identify if one particular detergent was more suitable for the fibres. The data was presented in graphs and tables to aid understanding and the student's *t*-test was used to statistically analyse the differences between results. Evaluation of results has enabled the hypotheses, outlined in 4.1., to be proved or disproved. These hypotheses, together with the research questions will be answered in the main research conclusion, where a summary of findings will be made and recommendations provided.

Conclusion

Evaluation of Research Project

The aim of this research was to investigate the effects of wet cleaning synthetic fibres by comparing different wash solutions to assess their effectiveness of soil removal and to highlight any damage caused to the fibres as a result of the process. The aims and objectives were fulfilled and a summary of the research project is outlined below.

The review of literature provided the topic for this dissertation by identify a gap in the conservation research. It was recognised that further research was needed for the interventive treatments of objects made from and containing synthetic fibres and wet cleaning was considered a beneficial area to investigate further. The literature review also provided information on conservation testing for wet cleaning and soil removal, through the help of past publications, which aided the selection of fibres, stains and detergents used in this research.

Research into the properties of man-made fibres identified how they might react to the wet cleaning process, in terms of changes to tensile strength. Information relating to the attraction or resistance of certain stains for the different fibres was also examined. Furthermore, it highlighted a number of differences between semi-synthetic and pure synthetic fibres, caused by the manufacturing process. The textile science literature enabled a number of hypotheses to be proposed and these will be examined later in this conclusion.

The preparation of test specimens and the experiments were conducted in as controlled a manner as possible. Although it was not practical to control the environment the temperature and relative humidity were monitored and recorded for future reference. The apparatus used for staining the test specimens was successful and the standardised wet cleaning procedure helped to keep the testing relatively consistent. During the analysis of soil removal test specimens it was found that the application of stain 2, containing soot particles, varied between test specimens. This variable would need to be reduced for any further testing by ensuring the same amount of particulate soiling was present on all test specimens. The artificial ageing process worked well, helping to fix the stains so they would remain bonded to the fibres when initially placed it the wash solution.

The evaluation of results was improved by the combination of visual and statistical analysis, making it possible to fully analyse the test specimens for differences in soil removal and tensile strength. The research questions will now be answered and some guidelines offered on wet cleaning synthetic fibres. This will be followed by the hypotheses (4.1.), which will be proved or disproved to aid future conservation of synthetic fibre objects.

Basic Guidelines for Conservators

The initial research questions are outlined in 3.1. The answers are presented below in the form of guidelines for conservators wishing to wet clean synthetic fibres:

- The practice of wet cleaning is suitable for all synthetic fibres tested for this research
- The washing process slightly affects the strength of cellulose acetate and viscose rayon, meaning more care would need to be taken when cleaning these fibres
- Either anionic or non-ionic detergent is suitable for soil removal on acetate, viscose rayon or polyester. However, anionic detergent may cause more damage to semi-synthetics, in particular acetate
- Anionic detergent has better cleaning properties for nylon and it is also less damaging to the fibre's strength than other wash solutions
- The strength of polyester is not affected by any treatment and both detergents work to remove water-soluble stains
- Anionic detergent is deemed better at soil removal for water soluble stains but is less effective at removing oil based stain.
- It is important to consider both the fibre type and the stain prior to making a detergent choice.

Hypotheses i, ii, and iii were all confirmed to be true, as identified by the research questions. Hypotheses iv produced mixed results. Orvus WA® paste was more effective at soil removal for the semi-synthetic fibres but also worked to remove stains on nylon and polyester. While Dehypon LS45® removed certain stains from both semi- and synthetic fibres if was not more effective than anionic. However, it worked to reduce stain 2 on the synthetic fibres, more effectively than anionic.

Suggestions for Future Research

This investigation has identified a number of possible areas for future research, in relation to wet cleaning and soil removal of synthetic fibres. The suggestions are listed below:

- Examine a larger range of stains, covering all categories of soiling, to further compare the effectiveness of soil removal for different detergents
- Investigate the benefits of detergent mixtures for soiled synthetic fibres
- Evaluate the importance of wash bath temperature in removing stains from synthetic fibres
- Test synthetic fabric blends to see how these fibres compare to individual fibre types

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Appendix 1

Materials and Suppliers

Materials and Suppliers

Fabrics

Acetate (Acetate Taffeta Lining)

MacCulloch & Wallis
25-26 Dering Street
LondonC
W1S 1AT
http://www.macculloch-wallis.co.uk/

Viscose Rayon (Spun Rayon)

Whaleys (Bradford) LTD
Harris Court
Great Horton
Bradford
West Yorkshire
BD7 4EQ
http://www.whaleys-bradford.ltd.uk/

Nylon (Nylon Lining, 60gsm)

UK Fabrics Online
http://ukfabricsonline.com/

Polyester (Polyester Taffeta)

Whaleys (Bradford) LTD
Harris Court
Great Horton
Bradford
West Yorkshire
BD7 4EQ
http://www.whaleys-bradford.ltd.uk/

Appendix 2

Wet Cleaning Record Sheet

Wet Cleaning Record Sheet

This is an example of the record sheets used during the standardised wet cleaning tests for both soil removal and tensile strength test specimens.

Detergent calculations

1.75g Orvus WA® Paste in 1 litre of water (5 x cmc)

3g Dehypon LS45® in 1 litre of water (5 x cmc)

1 litre of wash solution was made up for 2 baths of 500ml each

Wet cleaning process

Wet Cleaning Stage	Cycle	Time (mins)	Temp	pH	Notes
Wash Solution (Soft tap water, Anionic detergent or Non-Ionic detergent)	Soak front	15			
	Sponge front	15			
	Soak back	15			
	Sponge back	15			
Soft Water Rinses (Water changed after each 5 minute rinse)	Rinse back	5			
	Rinse back	5			
	Rinse front	5			
	Rinse front	5			
Deionised Water Rinse	Soak	10			
Drying	Placed in blotter	5			
	Total:	1hr 35mins			

Average temperature (^{o}c) and pH for wash solutions and water

Water (used for wash solution and rinses) - pH 6.93 temp 22.5 ^{o}c

Orvus WA® Paste - pH 7.14 temp 23 ^{o}c

Dehypon LS45® - pH 6.89 temp 23 ^{o}c

Deionised water - pH 4.38 temp 24 ^{o}c

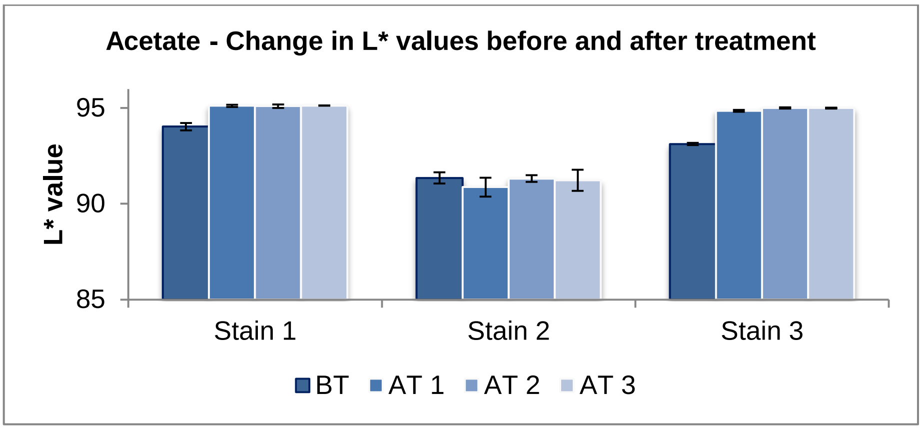
Appendix 3

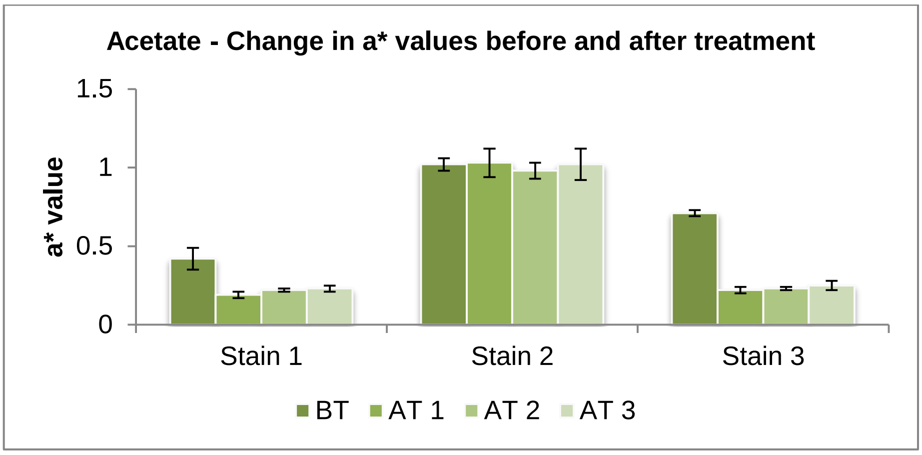
Colour Readings and Soil Removal Graphs

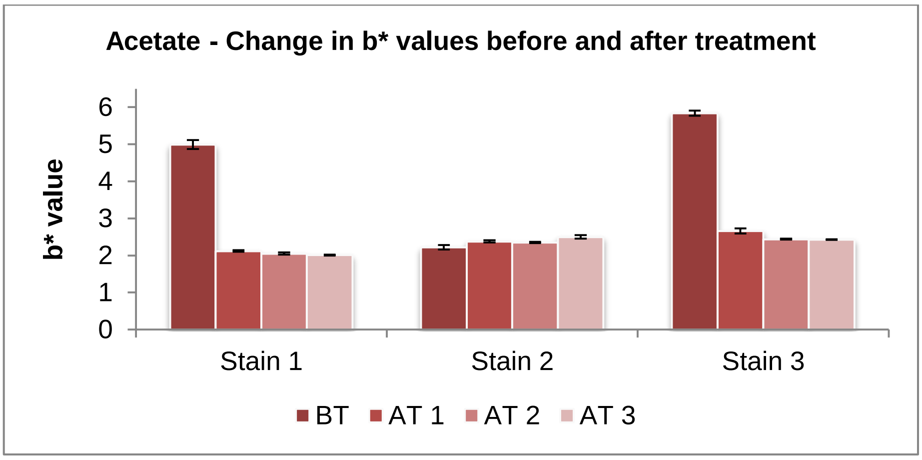
Colour Readings and Soil Removal Graphs

The colour readings taken from the Chroma meter were translated into tables to preserve the data and make it more readable during analysis. Tables were then used to create the graphs. Tables of L* a* b* readings for the before and three after treatments are presented below for each fibre along with three histograms showing the difference in treatments for the L*, a* and b* values.

Acetate







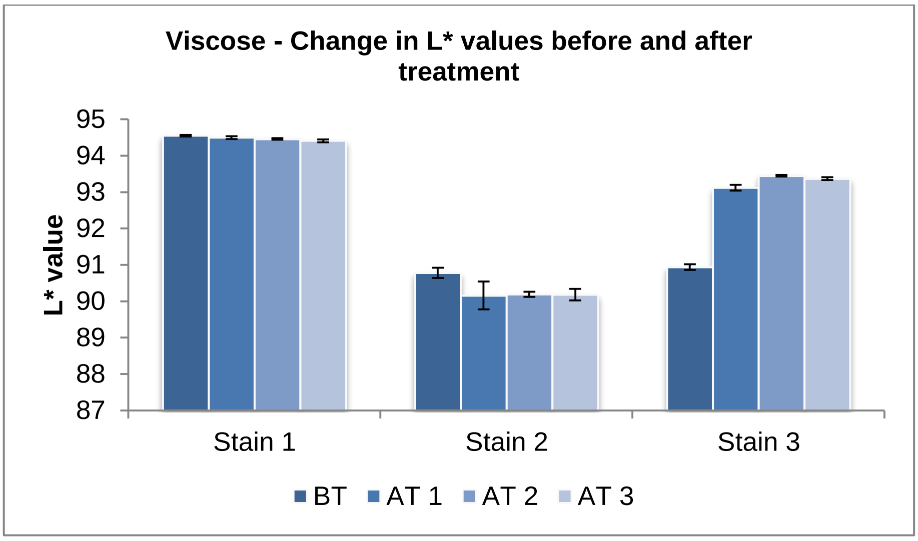
Acetate														
Results from treated samples: Before Treatment = After Ageing. Treatment = 1 - Water, 2 - Anionic, 3 - Non-ionic														
		Before Treatment				Treatment 1			Treatment 2			Treatment 3		
Stain	Sample	L*	a* (+)	b* (+)	Sample	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)
1 – orange juice	Control	94.15	0.38	5.03	1	95.13	0.20	2.13	94.96	0.24	2.09	95.12	0.22	2.01
	1	94.08	0.39	5.11	2	95.03	0.22	2.15	95.11	0.22	2.02	95.13	0.23	2.03
	2	93.74	0.52	4.81	3	95.15	0.17	2.11	95.15	0.21	2.02	95.12	0.25	2.00
	3	94.15	0.37	5.00	4	95.16	0.18	2.10	95.16	0.22	2.05	95.13	0.20	2.01
	Average	**94.03**	**0.42**	**4.99**	Average	**95.12**	**0.19**	**2.12**	**95.10**	**0.22**	**2.05**	**95.13**	**0.23**	**2.01**
2 – oil & soot	Control	91.04	1.00	2.18	1	91.45	0.92	2.36	91.13	1.01	2.36	90.73	1.13	2.55
	1	91.74	1.01	2.19	2	90.41	1.11	2.43	91.43	0.93	2.32	91.99	0.90	2.44
	2	91.36	0.98	2.31	3	91.11	0.99	2.36	91.21	1.04	2.33	90.94	1.07	2.55
	3	91.26	1.08	2.21	4	90.49	1.11	2.35	91.49	0.95	2.37	91.26	0.99	2.46
	Average	**91.35**	**1.02**	**2.22**	Average	**90.87**	**1.03**	**2.38**	**91.32**	**0.98**	**2.35**	**91.23**	**1.02**	**2.50**
3 – coffee	Control	93.09	0.73	5.91	1	94.86	0.22	2.68	95.06	0.22	2.45	94.97	0.29	2.41
	1	93.10	0.71	5.88	2	94.78	0.22	2.76	95.02	0.24	2.46	95.01	0.23	2.44
	2	93.07	0.73	5.78	3	94.85	0.24	2.58	94.99	0.23	2.42	94.97	0.24	2.43
	3	93.21	0.68	5.77	4	94.90	0.19	2.62	94.98	0.23	2.43	95.03	0.23	2.44
	Average	**93.12**	**0.71**	**5.84**	Average	**94.85**	**0.22**	**2.66**	**95.01**	**0.23**	**2.44**	**95.00**	**0.25**	**2.43**

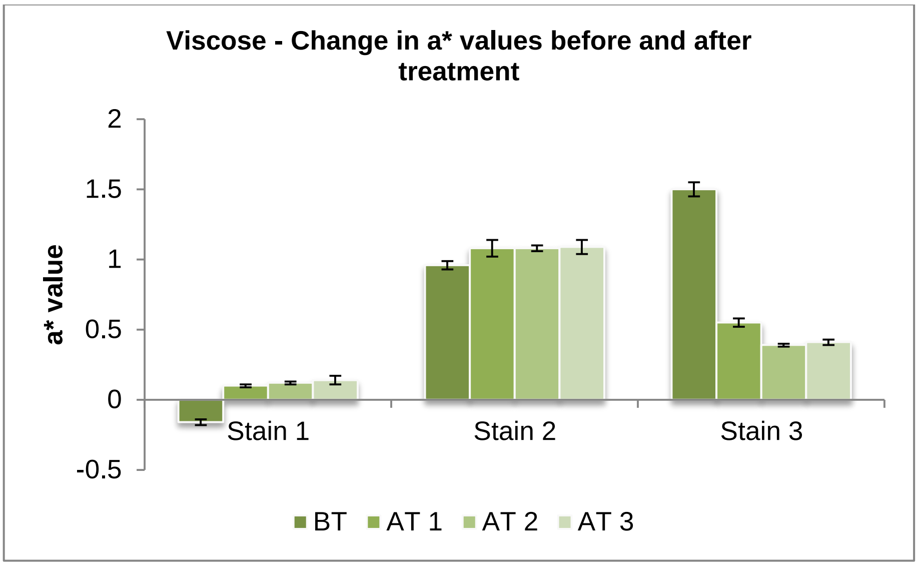
Viscose														
Results from treated samples: Before Treatment = After Ageing. Treatment = 1 - Water, 2 - Anionic, 3 - Non-ionic														
		Before Treatment				Treatment 1			Treatment 2			Treatment 3		
Stain	Sample	L*	a* (+/-)	b* (+)	Sample	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)
1 – orange juice	Control	94.57	-0.15	4.29	1	94.52	0.08	3.04	94.42	0.11	3.03	94.36	0.14	3.01
	1	94.54	-0.19	4.25	2	94.52	0.09	2.98	94.48	0.10	2.94	94.47	0.17	2.93
	2	94.51	-0.14	4.21	3	94.43	0.11	3.04	94.45	0.13	2.99	94.38	0.10	3.04
	3	94.56	-0.18	4.22	4	94.51	0.12	2.97	94.47	0.12	2.92	94.42	0.15	2.95
	Average	**94.55**	**-0.16**	**4.24**	Average	**94.50**	**0.10**	**3.01**	**94.46**	**0.12**	**2.97**	**94.41**	**0.14**	**2.98**
2 – oil & soot	Control	90.66	+0.97	2.60	1	90.42	1.05	2.78	90.23	1.07	2.78	90.28	1.04	2.88
	1	90.94	+0.96	2.61	2	90.33	1.03	2.74	90.21	1.09	2.80	90.24	1.06	2.91
	2	90.65	+1.00	2.59	3	89.58	1.18	2.75	90.22	1.05	2.80	89.94	1.16	2.82
	3	90.88	+0.92	2.56	4	90.29	1.07	2.73	90.08	1.09	2.78	90.27	1.11	2.87
	Average	**90.78**	**0.96**	**2.59**	Average	**90.16**	**1.08**	**2.75**	**90.19**	**1.08**	**2.79**	**90.18**	**1.09**	**2.87**
3 – coffee	Control	90.89	+1.57	6.78	1	93.24	0.51	4.38	93.42	0.40	4.24	93.40	0.39	4.26
	1	91.06	+1.45	6.65	2	93.08	0.57	4.52	93.44	0.38	4.18	93.40	0.41	4.09
	2	90.95	+1.48	6.80	3	93.07	0.54	4.51	93.47	0.39	4.20	93.35	0.44	4.35
	3	90.87	+1.50	6.84	4	93.08	0.57	4.51	93.46	0.39	4.18	93.32	0.41	4.32
	Average	**90.94**	**+1.50**	**6.77**	Average	**93.12**	**0.55**	**4.48**	**93.45**	**0.39**	**4.20**	**93.37**	**0.41**	**4.26**

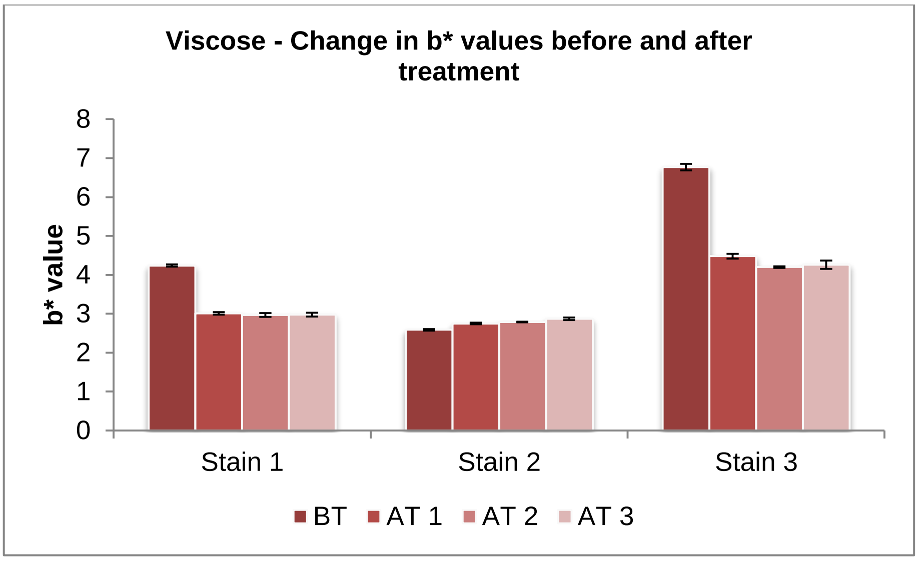
Nylon														
Results from treated samples: Before Treatment = After Ageing. Treatment = 1 - Water, 2 - Anionic, 3 - Non-ionic														
		Before Treatment				Treatment 1			Treatment 2			Treatment 3		
Stain	Sample	L*	a* (+)	b* (+)	Sample	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)
1 – orange juice	Control	91.53	1.57	7.78	1	94.68	0.07	3.39	94.76	0.13	3.29	94.48	0.11	3.29
	1	91.58	1.54	7.83	2	94.64	0.11	3.42	94.68	0.08	3.26	94.49	0.09	3.28
	2	91.52	1.55	7.83	3	94.68	0.09	3.40	94.74	0.09	3.28	94.50	0.08	3.27
	3	91.39	1.60	7.76	4	94.69	0.08	3.37	94.73	0.08	3.28	94.54	0.11	3.30
	Average	**91.51**	**1.57**	**7.80**	Average	**94.67**	**0.09**	**3.40**	**94.73**	**0.10**	**3.28**	**94.50**	**0.10**	**3.29**
2 – oil & soot	Control	89.83	1.13	2.81	1	89.22	1.23	2.85	89.49	1.25	2.91	89.47	1.24	3.03
	1	89.75	1.23	2.78	2	88.26	1.56	2.82	88.68	1.43	2.88	89.20	1.24	2.93
	2	90.06	1.14	2.79	3	89.27	1.30	2.83	89.47	1.19	2.92	89.23	1.34	3.02
	3	89.88	1.15	2.73	4	89.20	1.31	2.86	89.30	1.25	2.89	89.90	1.18	3.04
	Average	**89.88**	**1.16**	**2.78**	Average	**88.99**	**1.35**	**2.84**	**89.24**	**1.28**	**2.90**	**89.45**	**1.25**	**3.01**
3 – coffee	Control	90.12	2.08	7.15	1	92.82	0.61	5.28	94.41	0.15	3.67	92.55	0.73	5.35
	1	90.61	1.91	7.24	2	92.67	0.72	5.19	94.35	0.16	3.69	92.54	0.71	5.28
	2	90.16	2.08	7.06	3	92.74	0.67	5.19	94.49	0.10	3.65	92.57	0.71	5.24
	3	90.27	2.07	7.01	4	92.65	0.75	5.25	94.41	0.14	3.66	92.64	0.71	5.27
	Average	**90.29**	**2.04**	**7.12**	Average	**92.72**	**0.69**	**5.23**	**94.42**	**0.14**	**3.67**	**92.58**	**0.72**	**5.29**

Polyester														
Results from treated samples: Before Treatment = After Ageing. Treatment = 1 - Water, 2 - Anionic, 3 - Non-ionic														
		Before Treatment				Treatment 1			Treatment 2			Treatment 3		
Stain	Sample	L*	a* (+)	b* (+)	Sample	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)	L*	a* (+)	b* (+)
1 – orange juice	Control	94.47	0.27	4.73	1	95.66	0.05	2.32	95.75	0.08	2.26	95.63	0.10	2.20
	1	94.22	0.34	5.21	2	95.55	0.07	2.29	95.63	0.09	2.20	95.62	0.10	2.22
	2	94.33	0.34	5.10	3	95.58	0.07	2.27	95.63	0.08	2.24	95.54	0.09	2.21
	3	94.28	0.31	5.15	4	95.57	0.05	2.31	95.60	0.07	2.24	95.65	0.07	2.23
	Average	**94.33**	**0.32**	**5.05**	Average	**95.59**	**0.06**	**2.30**	**95.65**	**0.08**	**2.24**	**95.61**	**0.09**	**2.22**
2 – oil & soot	Control	90.41	1.18	2.44	1	91.49	0.90	2.70	89.85	1.14	2.87	91.31	0.91	2.76
	1	91.84	0.93	2.46	2	91.63	0.81	2.60	91.04	0.92	2.69	91.44	0.90	2.76
	2	90.90	1.03	2.29	3	90.89	0.91	2.61	91.13	0.93	2.73	90.90	0.98	2.84
	3	91.49	0.89	2.29	4	90.24	1.11	2.69	90.61	1.10	2.74	92.24	0.69	2.67
	Average	**91.16**	**1.01**	**2.37**	Average	**91.06**	**0.93**	**2.65**	**90.66**	**1.02**	**2.76**	**91.47**	**0.87**	**2.76**
3 – coffee	Control	93.41	0.58	5.77	1	94.90	0.11	2.81	95.23	0.13	2.53	95.22	0.14	2.44
	1	93.51	0.50	5.67	2	94.85	0.11	2.83	95.17	0.12	2.47	95.10	0.13	2.48
	2	93.32	0.61	5.86	3	94.75	0.19	2.87	95.18	0.15	2.50	95.10	0.11	2.50
	3	93.45	0.56	5.75	4	94.84	0.13	2.87	95.15	0.13	2.52	95.10	0.13	2.40
	Average	**93.42**	**0.56**	**5.76**	Average	**94.84**	**0.14**	**2.85**	**95.18**	**0.13**	**2.51**	**95.13**	**0.13**	**2.46**

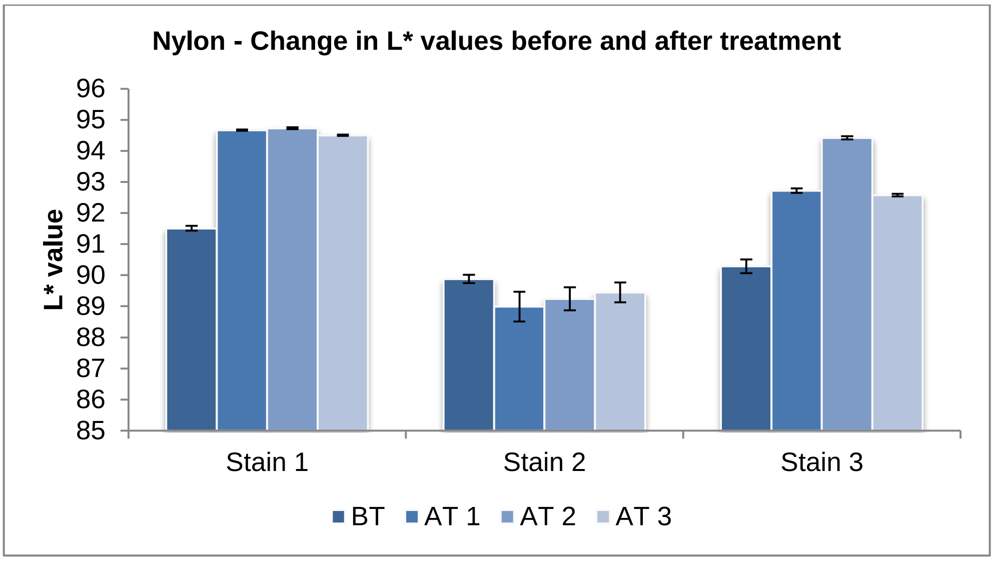
Viscose Rayon

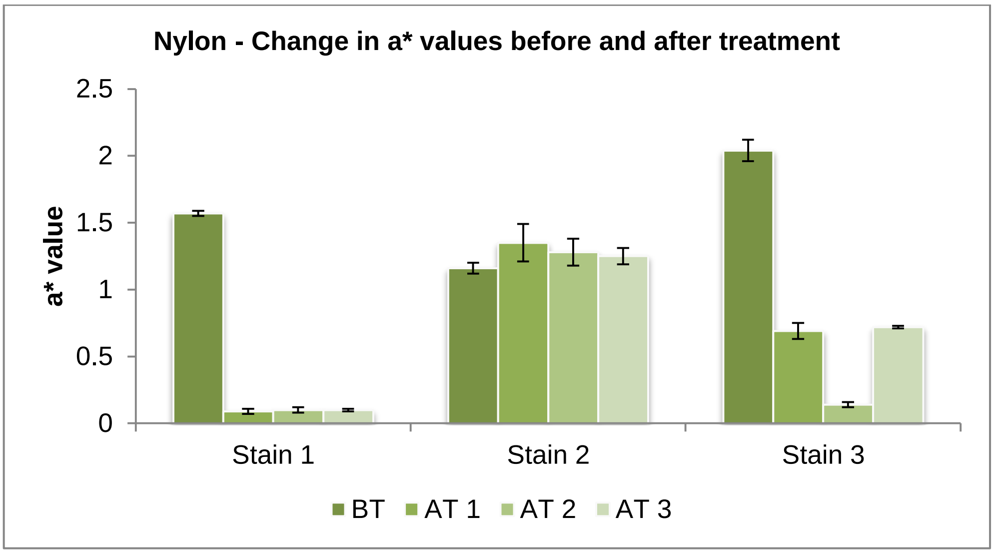


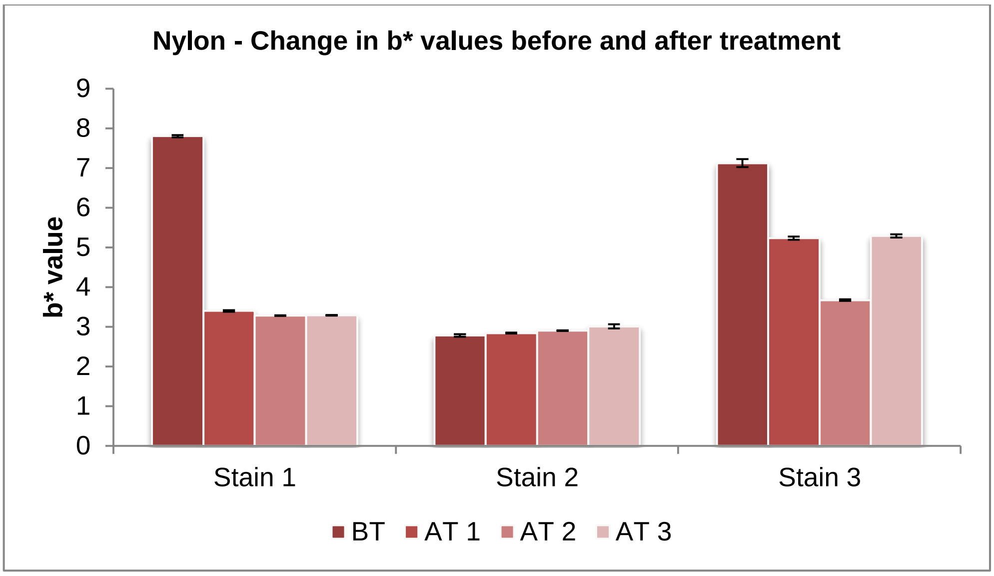




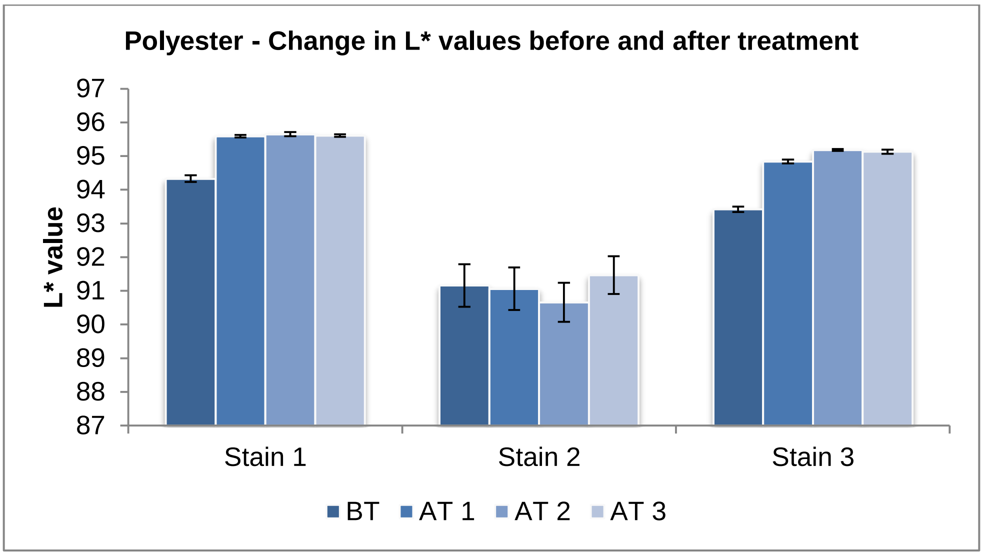
Nylon


Nylon - Change in L* values before and after treatment
L* value
96
95
94
93
92
91
90
89
88
87
86
85
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3

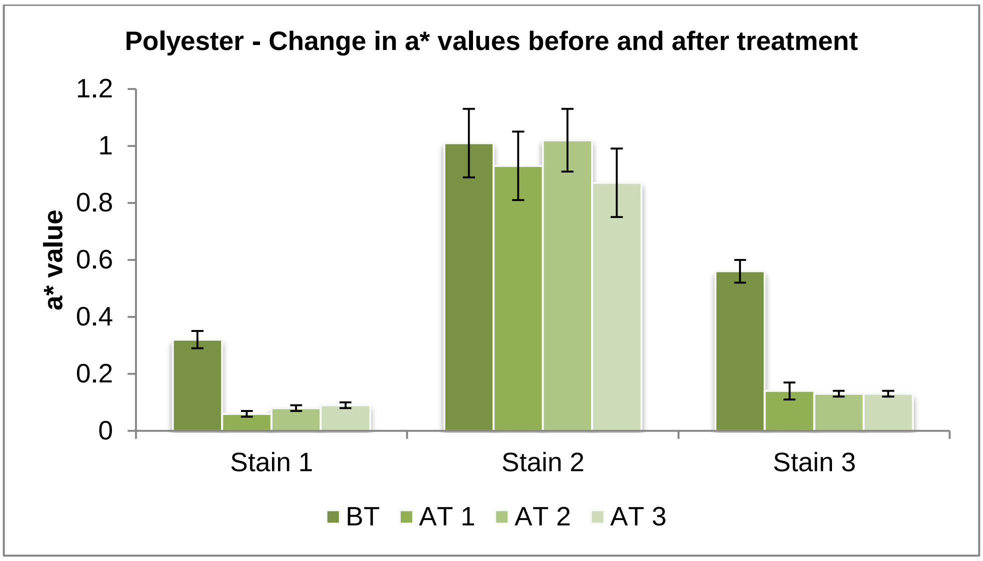

Nylon - Change in a* values before and after treatment
a* value
2.5
2
1.5
1
0.5
0
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3


Nylon - Change in b* values before and after treatment
b* value
9
8
7
6
5
4
3
2
1
0
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3

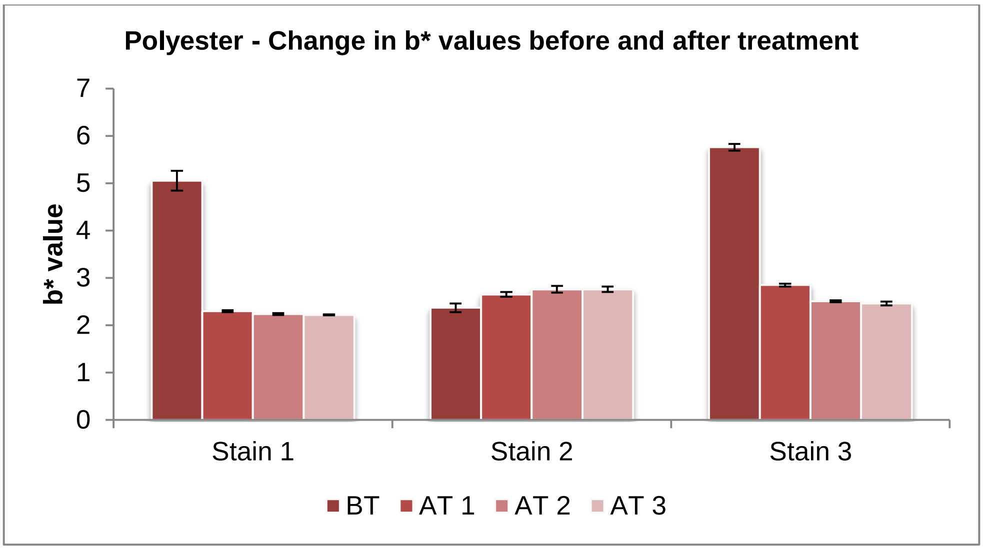
Polyester



Polyester - Change in L* values before and after treatment
L* value
97
96
95
94
93
92
91
90
89
88
87
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3



Polyester - Change in a* values before and after treatment
a* value
1.2
1
0.8
0.6
0.4
0.2
0
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3



Polyester - Change in b* values before and after treatment
b* value
7
6
5
4
3
2
1
0
Stain 1
Stain 2
Stain 3
BT
AT 1
AT 2
AT 3

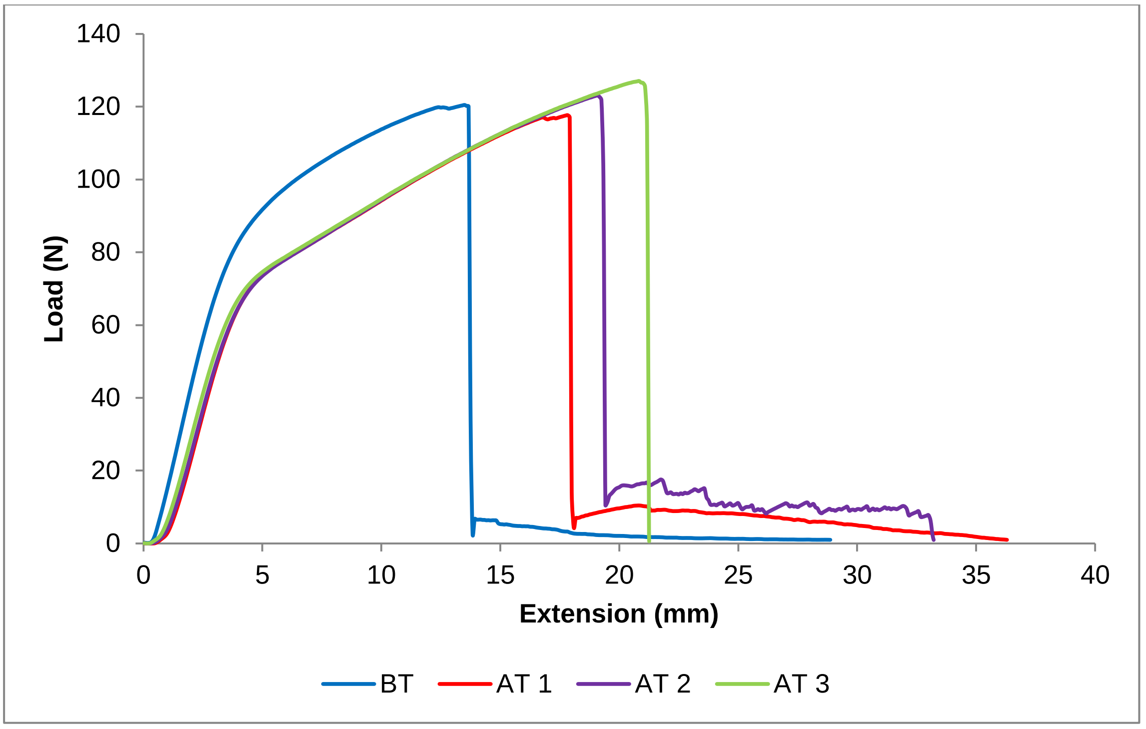
Appendix 4

Tensile Strength Test Results

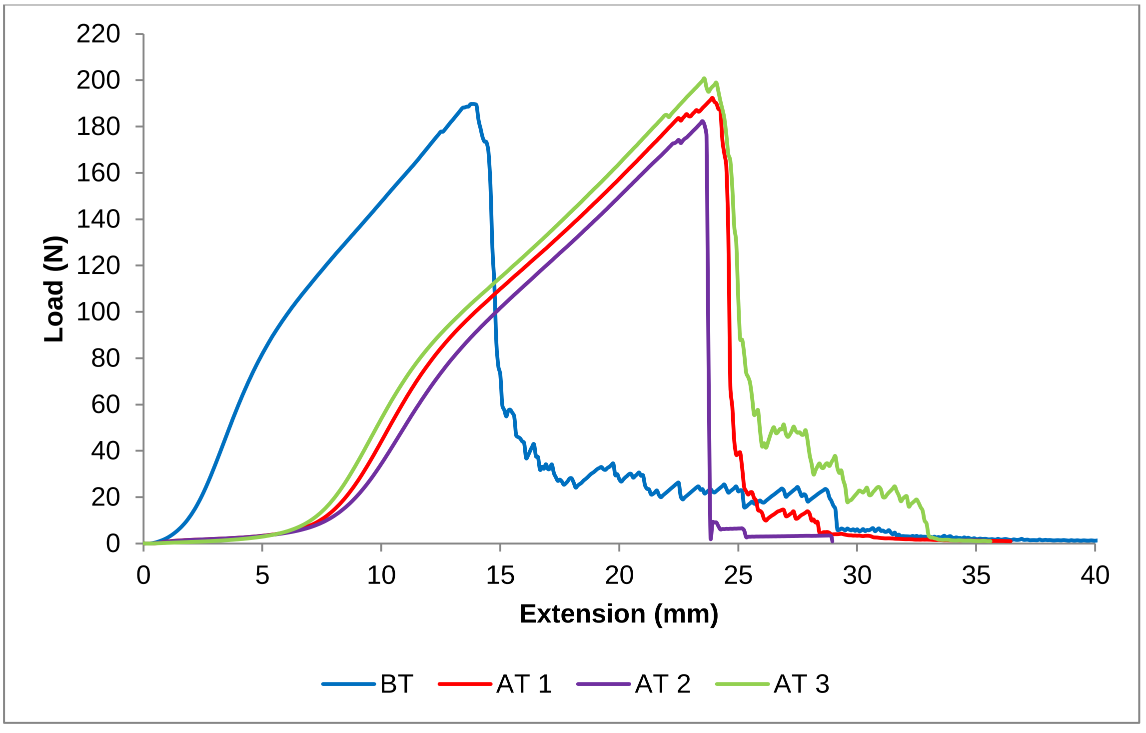
Tensile Strength Test Results

The tensile strength test graphs show the load-extension curve for before and after treatments for each fibre. The mean value was used for each of the treatments and the graphs produced in Microsoft Excel. All figures were taken from the tensile strength tester's Bluehill® software.

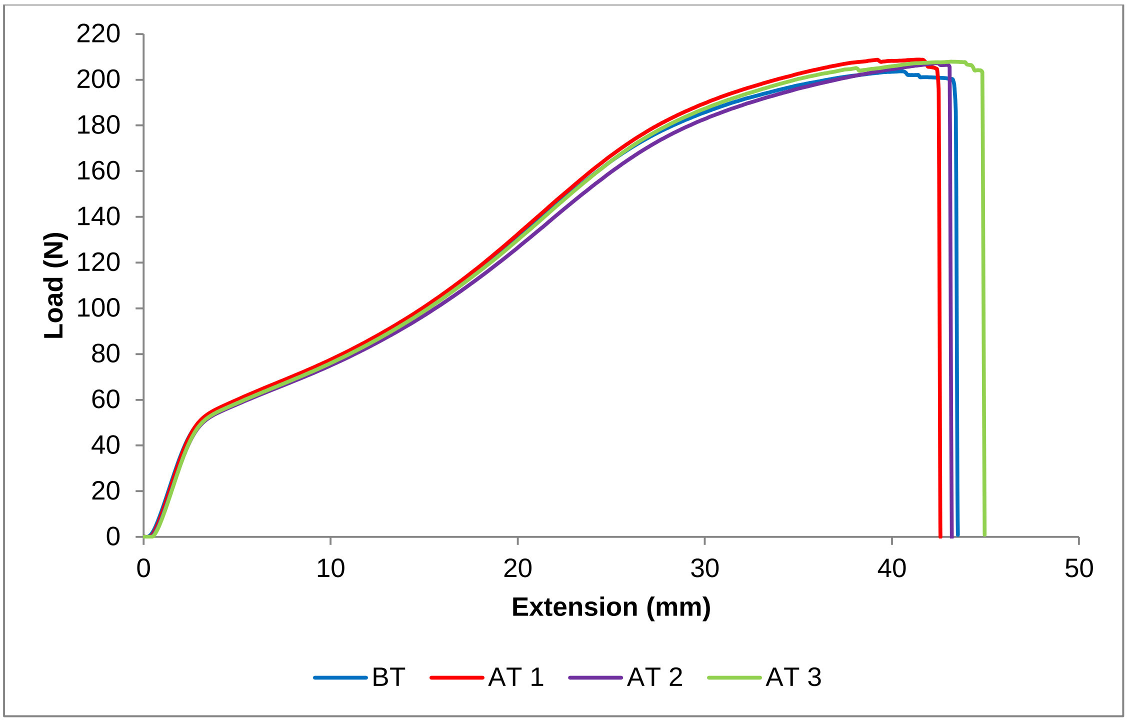
Acetate - Mean load-extension curves for before and after treatments



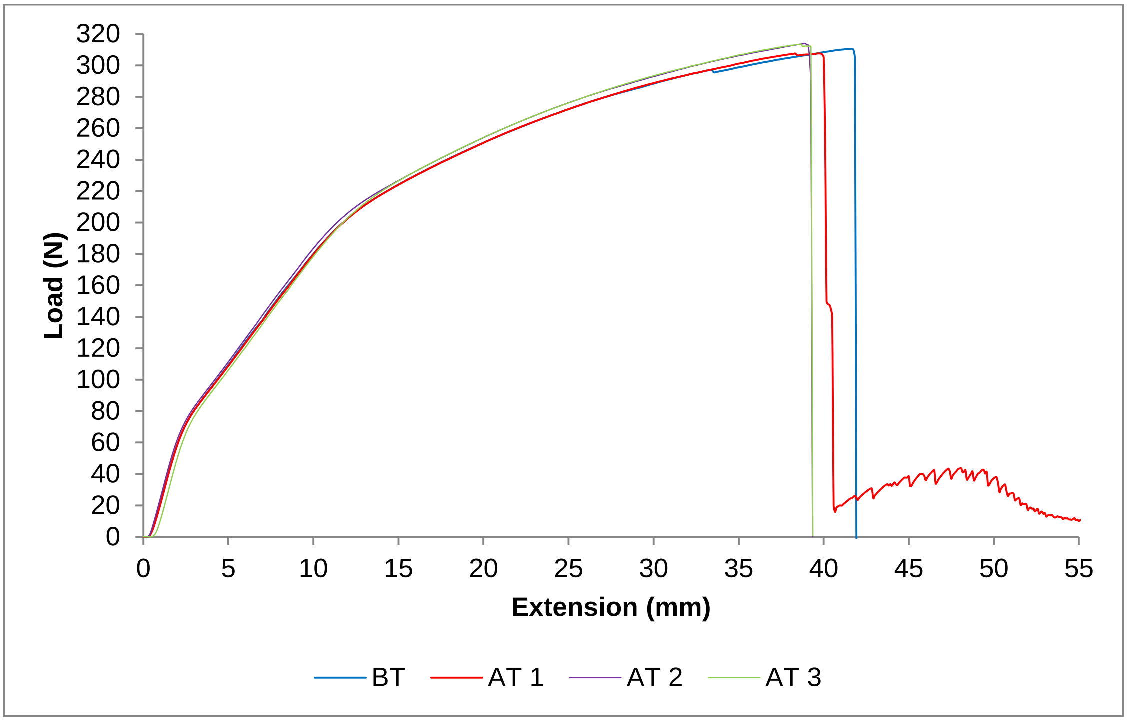
Viscose Rayon - Mean load-extension curves for before and after treatments



Nylon - Mean load-extension curves for before and after treatments



Polyester - Mean load-extension curves for before and after treatments



Appendix 5

Student's *t*-test Explanation and Results

Student's *t*-test Explanation and Results

The Student's *t*-test calculates the probability of two sets of data being significantly different. The *p* (probability) values p<0.05 (1 in 20), p<0.01 (1 in 100) and p<0.001 (1 in 1000) are used to show how significantly different two sets of data are. The smaller the number means the result is more significantly different. The student *t*-test was used to confirm the similarities or differences between before and after treatments as well as between the three after treatments. Both soil removal and tensile strength test specimens were analysed in this way. The tables below show the figures obtained from the Chroma meter or the tensile strength tester's Bluehill® software. NS on the table means there was no significant difference.

Soil removal test specimens

Acetate - L* value for stain 1

Test Pair	p value	p =
BT vs AT 1	0.00	<0.01
BT vs AT 2	0.00	<0.01
BT vs AT 3	0.00	<0.01
AT 1 vs AT 2	0.70	NS
AT 1 vs AT 3	0.82	NS
AT 2 vs AT 3	0.56	NS

Acetate - L* value for stain 2

Test Pair	p value	p =
BT vs AT 1	0.1568	NS
BT vs AT 2	0.8449	NS
BT vs AT 3	0.7179	NS
AT 1 vs AT 2	0.1697	NS
AT 1 vs AT 3	0.3650	NS
AT 2 vs AT 3	0.7849	NS

Acetate - L* value for stain 3

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.0023	<0.01
AT 1 vs AT 3	0.0041	<0.01
AT 2 vs AT 3	0.4838	NS

Viscose Rayon - L* value for stain 1

Test Pair	p value	p =
BT vs AT 1	0.1078	NS
BT vs AT 2	0.0030	<0.01
BT vs AT 3	0.0052	<0.01
AT 1 vs AT 2	0.1781	NS
AT 1 vs AT 3	0.0369	<0.05
AT 2 vs AT 3	0.1510	NS

Viscose Rayon - L* value for stain 2

Test Pair	p value	p =
BT vs AT 1	0.0407	<0.05
BT vs AT 2	0.0015	<0.01
BT vs AT 3	0.0016	<0.01
AT 1 vs AT 2	0.8879	NS
AT 1 vs AT 3	0.9021	NS
AT 2 vs AT 3	0.9788	NS

Viscose Rayon - L* value for stain 3

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.0027	<0.01
AT 1 vs AT 3	0.0041	<0.01
AT 2 vs AT 3	0.0183	<0.05

Nylon - L* value for stain 1

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.0410	<0.05
AT 1 vs AT 3	0.0001	<0.001
AT 2 vs AT 3	0.0001	<0.001

Nylon - L* value for stain 2

Test Pair	p value	p =
BT vs AT 1	0.0307	<0.05
BT vs AT 2	0.363	<0.05
BT vs AT 3	0.0700	NS
AT 1 vs AT 2	0.4545	NS
AT 1 vs AT 3	0.1714	NS
AT 2 vs AT 3	0.4225	NS

Nylon - L* value for stain 3

Test Pair	p value	p =
BT vs AT 1	0.0001	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0002	<0.01
AT 1 vs AT 2	0.0000	<0.001
AT 1 vs AT 3	0.0238	<0.05
AT 2 vs AT 3	0.0000	<0.001

Polyester - L* value for stain 1

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.1838	NS
AT 1 vs AT 3	0.5795	NS
AT 2 vs AT 3	0.3446	NS

Polyester - L* value for stain 2

Test Pair	p value	p =
BT vs AT 1	0.8351	NS
BT vs AT 2	0.2878	NS
BT vs AT 3	0.4882	NS
AT 1 vs AT 2	0.3845	NS
AT 1 vs AT 3	0.3712	NS
AT 2 vs AT 3	0.0909	NS

Polyester - L* value for stain 3

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.0003	<0.01
AT 1 vs AT 3	0.0005	<0.01
AT 2 vs AT 3	0.1915	NS

Tensile strength test specimens

Acetate - Load at Failure

Test Pair	p value	p =
BT vs AT 1	0.6842	NS
BT vs AT 2	0.0474	<0.05
BT vs AT 3	0.0432	<0.05
AT 1 vs AT 2	0.0225	<0.05
AT 1 vs AT 3	0.0392	<0.05
AT 2 vs AT 3	0.7310	NS

Acetate - Extension at Failure

Test Pair	p value	p =
BT vs AT 1	0.0100	<0.01
BT vs AT 2	0.0030	<0.01
BT vs AT 3	0.0018	<0.01
AT 1 vs AT 2	0.2212	NS
AT 1 vs AT 3	0.1128	NS
AT 2 vs AT 3	0.5595	NS

Viscose Rayon - Load at Failure

Test Pair	p value	p =
BT vs AT 1	0.5731	NS
BT vs AT 2	0.0066	<0.01
BT vs AT 3	0.2643	NS
AT 1 vs AT 2	0.0049	<0.01
AT 1 vs AT 3	0.3954	NS
AT 2 vs AT 3	0.0211	<0.05

Viscose Rayon - Extension at Failure

Test Pair	p value	p =
BT vs AT 1	0.0000	<0.001
BT vs AT 2	0.0000	<0.001
BT vs AT 3	0.0000	<0.001
AT 1 vs AT 2	0.8661	NS
AT 1 vs AT 3	0.6866	NS
AT 2 vs AT 3	0.6528	NS

Nylon - Load at Failure

Test Pair	p value	p =
BT vs AT 1	0.2370	NS
BT vs AT 2	0.5784	NS
BT vs AT 3	0.2771	NS
AT 1 vs AT 2	0.4606	NS
AT 1 vs AT 3	0.8304	NS
AT 2 vs AT 3	0.6327	NS

Nylon - Extension at Failure

Test Pair	p value	p =
BT vs AT 1	0.0246	<0.05
BT vs AT 2	0.5489	NS
BT vs AT 3	0.0001	<0.001
AT 1 vs AT 2	0.5491	NS
AT 1 vs AT 3	0.0205	<0.05
AT 2 vs AT 3	0.1037	NS

Polyester - Load at Failure

Test Pair	p value	p =
BT vs AT 1	0.9005	NS
BT vs AT 2	0.4852	NS
BT vs AT 3	0.3518	NS
AT 1 vs AT 2	0.3512	NS
AT 1 vs AT 3	0.2413	NS
AT 2 vs AT 3	0.4667	NS

Polyester - Extension at Failure

Test Pair	p value	p =
BT vs AT 1	0.5787	NS
BT vs AT 2	0.9897	NS
BT vs AT 3	0.8559	NS
AT 1 vs AT 2	0.4679	NS
AT 1 vs AT 3	0.5984	NS
AT 2 vs AT 3	0.7352	NS

Appendix 6

Risk Assessment