‘Like with like’: A comparison of natural and synthetic stitching threads used in textile conservation.

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Abstract

This research aimed to determine optimum thread types used in textile conservation by quantitatively evaluating tensile strength and damage inhered to conserved samples. A literature review and questionnaire sent to textile conservators were used to establish the most commonly used threads for laid-thread couching treatments and the rationale behind thread choice. Most common threads found were two-ply hair silk and Tetex (formerly Stabiltex) as well as fine polyester, silk, and cotton varieties.

Three natural fibre plain-weave artefact samples conserved with five different thread types (lace cotton, hair silk, organsin, Skala and Tetex) using laid-thread couching were tensile strength tested or subjected to a fixed-load experiment for two weeks. Results were evaluated with high-magnification images and scanning electron microscope (SEM). The fixed-load experiment determined that longer periods of time created more damage, even with lighter loads. Lace cotton and hair silk gave the best results for textile conservation use on natural fibre artefacts, whereas the polyester threads gave the highest damage results. Many conclusions were drawn from this research, however, further research is required to quantify some observations, such as stitching effects, and to broaden the research's scope within textile conservation.

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II. List of abbreviations

Tetex: Tetex TR, or formally known as Stabiltex

SEM: scanning electron microscope

MFA: microfibril angle

DP: degree of polymerisation

dtex: Decitex

RH: Relative humidity

PET: Polyethylene terephthalate

BHET: bis-(2-hyroxyethy) terephthalate

N: Newton

CRE: constant rate of extension

SD: Standard deviation

ISACC: Imaging Spectroscopy and Analysis Centre

CTC: Centre for Textile Conservation

1. Chapter 1. Introduction

The inspiration for this dissertation project began with the author's background in fashion design and sewing. Within the fashion industry there is an overall consensus that seams (and therefore threads) should break before damaging the material. This is because it is possible to repair a failed seam, but generally it is not possible to repair the fabric without major alterations. However, it was found that in textile conservation, threads are generally chosen by a different set of rules in which sometimes other aspects, such as invisibility, outweigh the physical properties. It was thus the desire of the author to determine how and why thread choices are made in conservation and to perform tests that would improve the understanding of the relationship between the thread and the artefacts being conserved.

Threads in textile conservation are primarily used to consolidate areas of weakness or loss within a textile artefact by means of stitching. They can also be used for stitching the artefact to a display or storage mount which may be placed under force in the future, such as the force of gravity from vertical display. It is thought by some conservators, in certain countries particularly, that synthetic materials are too strong for natural fibre textiles and may cause excess damage to the artefacts. The opposing view is that the synthetics used are fine enough to move with the textile and would not cause any more damage than a natural fibre thread. To gain more information, the opposing views were researched within the literature and a questionnaire sent to textile conservators to give a basis for the current level of knowledge or opinions on the subject.

Within the conservation profession, there has been a long-standing debate concerning like-with-like materials. Generally, this refers to the use of a conservation material with similar properties as the artefact being conserved. The theory is that the similar material is more sympathetic with the properties of the artefact. The opposing view is open to more material varieties which can allow more choice when deciding upon the most suitable material for treatments. Though this debate has some very strong subjective views with hypotheses, as of yet there has not been many experiments to determine if one theory or hypothesis is more appropriate than the other.

The purpose of this dissertation was to consider the like-with-like debate focusing on the threads used in textile conservation. If indeed damage is being done to the artefacts by either material choice, this is pertinent information that conservators need to be aware of in order to most appropriately treat the artefacts.

As this is one of the first research projects to test threads and their relationship with the artefacts, a simple methodology with limited variables was required to give a starting point to a complex and diverse topic. This research focused on natural material artefacts conserved with laid-thread couched stitched supports utilising a range of thread types most commonly used in textile conservation. A series of tests were developed utilising a tensile strength tester, fixed-load testing and high-magnification evaluation techniques to determine the properties of the samples and what damage was done to the samples when they were placed under strain. The use of these forms of analysis should minimise human subjectivity in the results.

1.1. Research questions

The following questions were formulated in order to provide textile conservators with quantitative data on the relationship between the stitching threads used and the textile artefacts.

- Can the point of damage on an artefact be determined through tensile strength testing, and if so, what is it and is it consistent between the different samples?
- What is the most appropriate thread type for natural fibre artefacts, and can this be objectively determined?
- Can the 'like with like' theory related to threads in conservation be proved or disproved by mechanical strength testing and how does this research contribute to the debate?

1.2. Research objectives

In order for the aims of the overall research to be accomplished, several objectives were developed:

- Complete a comprehensive literature review of the stitching threads and fabric supports used in textile conservation highlighting previous research.
- Distribute and analyse a questionnaire to determine current conservation trends regarding thread choice including the prevailing rationale behind the choices and identification of regional and institutional trends.
- Use tensile strength testing to quantitatively measure characteristics of both thread and samples conserved with laid-thread couching.
- Evaluate conserved samples with microscopy and scanning electron microscope (SEM) to objectively determine how damage occurs and at what point in their extension.

1.3. Report outline

This dissertation is structured into seven chapters with **Chapter One** introducing the project. Chapters Two through Four give a background into the subject. **Chapter Two** consists of a literature review focusing on threads used in textile conservation and past quantitative research that aided in developing the experimental methodology. An evaluation of the questionnaire is presented in **Chapter Three,** which gives an understanding of current trends and preferences held by practicing conservators. **Chapter Four** gives a background into the fibre structures used in the experiments. **Chapter Five** outlines and discusses the experimental methodology which begins with tensile strength testing of the threads individually. The other pretests included were tensile testing of the fabrics individually and tensile strength testing of couched samples on new fabrics to their breakpoint. The main experiment of the conserved artefact samples is explained in the next section with the final section describing a time dependant fixed-load test of the conserved artefact samples. **Chapter Six** presents the results from all the experiments outlined in Chapter Five and discusses and evaluates the results in relation to each other. **Chapter Seven** summarises the research as a whole taking into account the research questions provided in Chapter One, discusses the implications for how this research can benefit the textile conservation profession and highlights what further research is required.

2. Chapter 2. Literature review

The objective of the literature review was to gather, examine, and consolidate information on thread types currently and previously used in conservation so an appropriate experiment methodology could be established. This chapter gives context and an understanding of how this dissertation's research builds on the current literature and body of knowledge.

2.1. The current literature

While there is little conservation literature pertaining to this dissertation, a few relevant publications and studies were found. There are more sources available discussing the choices between synthetic and natural fibre threads, or the choice between stitching or adhesive techniques, than the relationship of the threads to the artefacts.[1] The area with the most quantitative research performed was on support fabrics, but not the threads which were used within the studies.[2] [3] Sources from the textile industry were also examined as there has been extensive research on yarn properties and how they affect seams and overall garment performance. The area in which one should find the most information and rationale would be within case studies and documentation of past stitching treatments. Unfortunately, these studies frequently only state what thread was used and any rationale behind the choice was generic and not well explained. There is a definitive lack within the literature focusing on quantitative tests on threads and how they affect and interact with the artefacts they are supporting.

2.2. Types of threads

To determine the most pertinent threads to test, the literature was most useful in highlighting the most commonly used threads in textile conservation. Since synthetic threads became more popular in the mid 20th-century, conservators have been experimenting and questioning which thread types are best suited for their particular treatments. The limited

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[1] Hanna Jedrzejewska, "Problems in the Conservation of Textiles: Needle versus Adhesive (1981)," in *Changing Views of Textile Conservation*, ed. Mary M. Brooks and Dinah D. Eastop, 148-152 (Los Angeles: Getty Conservation Institute, 2011).

[2] Mary Brooks et al., "Supporting Fragile Textiles," in *Lining and Backing: the Support of Paintings, Paper, and Textiles. Papers delivered at the UKIC Conference 7-8 November 1995*, ed. Andrew Durham, 5-13, (London: The United Kingdom Institute for Conservation, 1995).

[3] Margaret Ordonez, and Alfred Ordonez, "Evaluation of Mounting Techniques Used on Vertically Hung Textiles," in *ICOM-CC 7th Triennial Meeting Preprints, Copenhagen, 10-14 September 1984*, ed. D. de Froment, 84.9.38-84.9.41, (Paris: The International Council of Museums, 1984).

amount of literature with quantitative tests, which generally tested a range of threads,[4] as well as literature that explained stitching techniques,[5] [6] highlighted commonly used threads. Nevertheless, the latter generally focused on the differences between natural and synthetic not always on specific types of threads. Other sources that helped determine which threads are used were within case studies, and though these show a range of threads used, the rationale for the choice is not always explained.[7] The most commonly used threads for stitched couching treatments were: a fine silk thread, generally hair silk, and a fine drawn polyester thread such as Tetex (formerly Stabiltex). Other options were also used, such as fine cotton threads and other types of fine polyester and silk threads. Nylon threads seem to have been avoided as they were proven early on to cut through delicate artefact fibres and their chemical stability is questionable.[8]

2.3. Thread preferences

Within the literature, ever since conservators began implementing synthetic threads into their treatments, opinions as to whether synthetic or natural fibres are more appropriate for artefacts have generally been very strong. One of the first sources that gave guidelines on thread choice was by Leene (1972) who explains that although fine silk yarns were the preferred thread to be used with a silk artefact, they were becoming more difficult to find and could therefore be substituted with fine synthetic filament yarns (nylon, polyester).[9] This was the only source found to suggest nylon. In this work, a greater emphasis was based on the thread fineness than its chemical makeup. This source may also be one of the first to relay the belief held by many conservators that the threads should break before the artefact. It notes that this was derived from the textile industry belief in which the thread should break before the seam, thus preventing damage to the material. Leene goes on to state that this would almost never be an issue with the type of work conservators do as the artefacts would not be under enough strain to cause damage.[10]

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[4] Shirley Ellis, “A Preliminary Investigation of the Tensile Properties of Yarns Used for Textile Conservation,” *Textile Conservation Newsletter, Supplement Spring,* (1997).

[5] Mechthild Flury-Lemberg, “Conservation with Needle and Thread (1988),” in *Changing Views of Textile Conservation,* ed. Mary Brooks and Dinah Eastop, 168-174, (Los Angeles: Getty Conservation Institute, 2011).

[6] Sheila Landi, “Support and Consolidation,” in *The Textile Conservator’s Manual*, (Oxford: Butterworth-Heinemann, 1992), 117.

[7] Gillian Owens, “Ethics in Action: Conservation of King James II’s Wedding Suit,” *V&A Conservation Journal 26* (January 1998), http://www.vam.ac.uk/content/journals/conservation-journal/issue-26/ethics-in-action-conservation-of-king-james-iis-wedding-suit/ (accessed January 12, 2013).

[8] Flury-Lemberg, 171.

[9] Jentina Leene, *Textile Conservation*, (London: Butterworth & Co, 1972), 140-141.

[10] Leene, 141-142.

Significant literature was derived from Leene's work, especially that of Flury-Lemberg (1988) and Landi (1992).[11][12] These sources developed Leene's theories and began to state preferences and rationale when choosing natural or synthetic threads. Both authors suggested that the chosen thread should be similar to the artefact's fibre as it would have the same properties and reactions with environmental fluctuations, especially when humidity is concerned. Through these sources it could be determined that a preference for either natural or synthetic fibres had evolved. Flury-Lemberg stated that all artificial fibres may be too strong for the weaker fibres of artefacts and could cut through these fibres.[13] In contrast, Landi suggested that fine polyester threads have a much greater tensile strength and life expectancy than natural fibres and therefore should be preferred.[14] These preferences and theories had developed by the beginning of the 21st-century, but many sources acknowledged the general lack of quantitative data available that could aid in the decision process for conservators to make an informed choice of material.[15][16] Currently, as a whole, there are definite preferences for either natural or synthetic fibres based on the variety of theories, but no empirical research has yet proven if either preference is better for certain artefacts.

2.4. Literature with quantitative data

Within the specific subject of how threads relate to the artefact, Landi (1988) was the only source to perform experiments.[17] Conserved samples were hung vertically by one edge and weights progressively added to the bottom of the samples to create a fixed load. Unfortunately, there were several pitfalls with this source in its usefulness to the profession. Most importantly, the results and experimental methodology were not clearly defined so reproducibility is not possible. In addition, this and other useful sources are difficult to obtain now as many were written for smaller publications no longer in circulation. However, it was instrumental in informing the methodology for the fixed-load test in this dissertation.

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[11] Flury-Lemberg, 168-174.

[12] Landi, "Support and Consolidation," 106-147.

[13] Flury-Lemberg, 171.

[14] Landi, "Support and Consolidation," 108.

[15] Frances Lennard and Patricia Ewer, *Textile Conservation: Advances in Practice*, (Oxford: Butterworth-Heinemann, 2010), 143-144 and 231-233.

[16] Barbara Appelbaum, "Choice of Treatment Materials," in *Conservation Treatment Methodology*, (Hoboken: Taylor & Francis: 2012), 315-349.

[17] Sheila Landi, "The Arguments For and Against the Use of Synthetic Fibres for Sewing in Textile Conservation," in *20th Century Materials, Testing and Textile Conservation,* (Harpers Ferry: Harpers Ferry Regional Textile Group, 1988) 47-51.

Several research projects have tested similar factors and are important for this dissertation. Most influential was Ellis (1997) who tested the tensile properties of the various threads used in textile conservation,[18] and Asai et al. (2008) who tested different support methods and stitch types on tapestry samples to determine support effectiveness and evaluate any damage caused.[19] For this dissertation, the experimental methodology and results from Ellis were used to inform the testing of the threads before performing tests on the conserved samples. Asai et al. wrote a clear, well structured article making their experimental methodology layout very useful as well as providing hints for recording the data; such as setting up a camera with close-up capabilities to record during the tensile testing.[20]

There were some other informative sources found for tensile strength testing and result interpretation, such as Nilsson (2005) which tested five different techniques that could affect supports on conserved costume.[21] However, the stitched samples made for the experiment were not all consistent creating another variable within the methodology. Many textile technology literature sources may also have been useful, such as Mori (1994). This is one of the more clearly written industry articles and it gives a good understanding of what types of tests are performed within the industry. These could then be related to threads used in conservation.[22] However, many of the sources from the textile industry are very technical and are more based on why the yarns affect seam quality as opposed to the damage that may occur when stressed.[23]

Though Ballard's article from 1996 did not perform experiments, it gave a clear context to how and why fibres and yarns react to tensile strength testing and how to interpret the results.[24] Within this research project, Ballard's work helped give an understanding to

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[18] Ellis.

[19] Kaori Asai, et al., "Tapestry Conservation Traditions: An Analysis of Support Techniques for Large Hanging Textiles," in *ICOM-CC 15th Triennial Conference, New Delhi, 22-26 September 2008, Preprints,* ed. Janet Bridgland, 967-975, (New Delhi: Allied Publishers, 2008).

[20] Asai.

[21] Johanna Nilsson, "A Survey of the Most Common Support Methods Used on Historical Costumes and a Preliminary Investigation of Tests Assessing the Quality of Conserved Fabrics," in *Scientific Analysis of Ancient and Historic Textiles: Informing Preservation, Display and Interpretation, Postprints*, ed. Rob Janaway and Paul Wyeth, 79-85, (London: Archetype, 2005).

[22] Miyuki Mori and Masako Niwa, "Investigation of the Performance of Sewing Thread," *International Journal of Clothing Science and Technology, Vol 6 No. 2/3* (1994): 20-27.

[23] Jelka Gersak, "Rheological Properties of Threads: Their Influence on Dynamic Loads in the Sewing Process," *International Journal of Clothing Science and Technology, Vol 7 Issue: 2* (1994): 71-80.

[24] Mary Ballard, "Hanging Out: Strength, Elongation, and Relative Humidity: Some Physical Properties of Textile Fibers," in *ICOM-CC 11th Triennial Meeting, Edinburgh, Scotland 1-6 September 1996, Preprints,* ed. Janet Bridgland, 665-669, (London: James & James, 1996).

why the different threads give different results; which can also enable conservators to predict damage and choose the most appropriate thread for a treatment.

2.5. Conclusion

Many sources within the current literature have called for further research and have focused upon the lack of available literature on this topic. Although there are preferences and theories behind certain thread choices, the quantitative data proving which threads, if any, are preferable has not been captured before this dissertation project.

3. Chapter 3. Qualitative research

3.1. Introduction

A questionnaire was used to determine how frequently and why each thread type used for laid-thread couching treatments is currently being used in conservation and to observe any regional or institutional trends.

3.1. The questionnaire

A short questionnaire consisting of four questions of either tick choices or short answers was sent to 33 textile conservators in the United Kingdom, Europe, and United States with a focus on institutions and freelance conservators in the UK and France (see Appendix 9.1 for the questionnaire). It was also circulated through an international textile conservation forum. 41 responses were received as outlined in table 3.1. Previous published questionnaires were referred to when writing the questionnaire and questions were formulated to be brief while gathering as much pertinent information as possible.[25]

UK	US	Continental Europe	Other
England 11	East coast 9	France 4	Australia 2
Scotland 5	West coast 2	Germany/Swiss 3	New Zealand 1
Ireland 1		Sweden/Finland 2	Brazil 1

Table 3.1: Questionnaire responses by region

3.2. Evaluation and results

As not a high response was received from conservators in France, the responses were organised into regions of: the UK, US, continental Europe, and other (Appendix 9.2 for detailed results). The results are based on these responses. It should be noted that the data was insufficient to be representative of the regions as a whole, but provided illustrative examples.

Each region's responses were evaluated and compared based on the four questions given in the questionnaire.

[25] Camille Myers Breeze, *A Survey of American Tapestry Conservation Techniques*, (Lowell, MA: American Textile History Museum, 2000).

Question one: What threads does your institution use for laid couching treatments?

All regions had some responses that included different types of silk, polyester and cotton threads (table 3.2). Silk types that were noted frequently in all regions were hair silk and monofilament. In the US, organsin and silk stitching threads by Tire and Mettler brands were also mentioned. Organsin was used most frequently in Europe. Skala was the only polyester type noted in all regions, but Tetex or polyester drawn from a fabric was used in all regions except Europe. Responses from the UK also used thicker Gütermann polyesters and Mara specifically. Mara was preferred to Skala as it is softer; which is because Mara is made of stapled polyester fibres instead of filaments. The US had the largest use of cotton threads with a variety of types, most frequently DMC brand embroidery floss. Europe was the only region that mentioned using a thin wool and lace linen thread on occasion. (See Appendix 9.3 material resource list).

	UK	US	Europe	Other
Silk	**28**	**10**	**9**	**4**
Hair silk/organsin	14	7	4	-
Monofilament	14	-	2	-
Thicker silk	-	3	-	-
Cotton/linen	**7**	**10**	**7**	**2**
Lace cotton/fine	6	-	6	1
Thicker cotton	1	5	-	-
DMC floss	-	5	-	1
Lace linen	-	-	1	-
Fine wool	**0**	**0**	**2**	**0**
Polyester	**34**	**10**	**4**	**6**
Skala	13	6	2	3
Tetex	13	3	-	3
Mara	5	-	-	-
Thicker Gütermann	3	-	-	-
Polyester fabric	-	1	-	-
Cotton/poly blend	**-**	**1**	**-**	**-**

Table 3.2: Threads currently used by textile conservators

Question two: Would you say you generally prefer 1. natural materials when treating objects over synthetics, 2. synthetics over natural materials, or 3. no preference?

Most respondents had no preference as seen in table 3.3, which was the majority in all regions except Europe where natural fibres were predominate. The UK had the highest responses in favour of synthetics.

An interesting response from the US was given by an institution which deals frequently with indigenous groups where sometimes they are requested to use natural fibres on indigenous artefacts.

Only one reply from Europe (Finland specifically) chose synthetics. For the other areas only one response from Australia chose natural while the other four had no preference.

	UK	US	Europe	Other
Natural	2	3	5	1
Synthetic	6	1	1	
No preference	9	7	3	4

Table 3.3: Question 2 answers

Question three: What are your reasons for using (or not using) these threads?

A variety of responses were received for this question, but some were recurring and corresponded with the replies to question two.

Some common replies from the UK in favour of synthetics were for their strength and durability, especially in uncontrolled conditions where silk threads had been seen to degrade in the past. One respondent was 'not of the opinion that the supporting thread should be weaker than the original' because it was thought removing a failed or degraded treatment was more damaging than the strength of the synthetic threads. Many responses also indicated their general ease of availability, colour matching, and invisibility on the object. The answers against synthetics were that they are too strong, hard, thick and shiny. Silk was preferred particularly for natural fibre objects due to having similar environmental reactions and visual properties. Cotton was not that favourable as it was generally too noticeable.

Similar responses were given from the US. For example, polyesters were preferred by some for being an inert material and for when invisibility was desired. In addition, they stated the artefacts conservators treat are not under such strain that a stronger thread would cause damage. Some other respondents desired synthetics as they would be easily identifiable as non-original. The responses in favour of natural fibres were similar to the UK as well, but also noted that they tend to flex better with the object, that the treatment should degrade with the object and there was a desire to not introduce too many different materials from the original. However, both some UK and US respondents specified they would not use Skala as it is too hard and unsympathetic or less flexible.

From Europe the main responses were that natural materials are preferred because of how the material ages, that its behaviour is known and it will break before the artefact. It was also described as dyeable and easy to stitch. Cotton was desirable as being more stable than silk and that both fibres 'catch' to the fabric while synthetics are too smooth and slip over the surface.

From the other regions again availability, dyeability, ease of stitching and fibre properties were all factors. Tetex was noted as not being dyeable and difficult to stitch, while Skala again was thought to be too strong.

Whether a respondent was for or against a certain thread type, a classification of factors influencing thread choice could be made from this data (table 3.4).

Time/cost restraints	Appearance	Physical properties
Availability	Invisibility	Ageing qualities (to last longer or degrade with the object)
Dyeability	Noticeable as different to original	Stronger or weaker than object
Ease of stitching		Controlled or uncontrolled environment
		Known fibre behaviours
		Environmental reactions similar
		'Catch' to fabric instead of slipping and 'cutting'
		Soft or hard texture

Table 3.4: Factors for thread choice

Question four: If you were given this object to treat (Appendix 9.1 for object photograph), which thread type would you likely chose for the laid couching and why? It is a 19th-century wool sampler and is to be backed with a cotton support fabric.

As it is difficult to choose a thread type based on a photograph, most respondents gave several choices that they would most likely use. Most from the UK chose Tetex for its fineness, strength and a good colour match would probably be achievable. Silk was the second most common answer for being easier to stitch, would not add a synthetic element and would be fine enough to not add new holes to the object when stitched. Polyester threads were part of 70% of the responses.

The US gave the most diverse set of responses, and one respondent would possibly not stitch the object. Silk was the most common choice, and natural fibre threads made up 60% of the responses and 33% synthetics. Two stated though they may chose Skala, and it may be too strong, with careful stitch tension it could be appropriate.

Only one response from Europe chose Skala for being thin, invisible and easy to stitch; while silk was the most common choice and a fine cotton second. One response said a thin wool may also be a good choice as it is not 'glossy'.

The other regions preferred silk or cotton if a good match was available and one response said Tetex or Skala if it were going on permanent display.

	UK	US	Europe	Other
Silk	8	5	5	4
Cotton	-	4	4	1
Tetex	11	2	-	1
Skala	6	3	1	1
Other	2 (Mara)	1 (no stitching)	1 (Wool)	-

Table 3.5: Thread choices for sampler

3.3. Conclusion

From the responses to the questionnaire, it was concluded that there are noticeable trends for thread preferences based on different regions. The UK has a slight preference for synthetic threads over natural fibres based on superior durability of synthetics. Within continental Europe there is a definite preference for natural fibre threads over synthetics based on their known ageing and physical properties and their similar properties to natural fibre artefacts. Conservators in the US and the other regions in this study tend to also use synthetics but in general gave a preference for using 'like with like' materials when possible.

Some of the main influences on thread choice were time and cost constraints and that there are limited thread options. As conservators are very dependent upon sourcing the materials, availability is a main concern, especially as some materials and manufacturers have gone out of production in the recent past. One respondent from the UK put it nicely that 'the more choice you have the more informed your decision will be.'

Although many responses were not the same or had different reasoning backing up the choices, a prevailing theme was that each object must be treated individually and conservators must make their choice of thread based upon the needs of the object and how it will be displayed or used in the future.

4. Chapter 4. Material background

4.1. Introduction

This chapter gives a brief background into the fibre properties which make up the threads and fabrics used in this research. The chemical makeup and physical properties of each fibre helped conceptualise what reactions occurred during testing at a molecular level. As fibres are stretched during tensile strength testing, their reactions are dependent upon their different chemical make-ups. This includes any degradation patterns and physical properties as well as various manufacturing processes, which are frequently unknown to the examiner.

4.2. Cotton

4.2.1. Chemical make-up

As shown in table 4.1, cotton is a cellulosic fibre derived from the seed of the plant family *Gossypium*. The fibres' characteristic twists and convolutions form from the cell wall collapsing as the fibre dries after harvesting. These characteristics allow the fibres to grip each other and resist being pulled apart. [26]

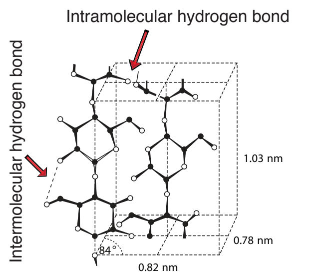
Chemistry	Fibre	Structure
Cellulosic plant fibre Linear polysaccharide polymer: molecular chain which can bend and twist	Cellulose fibril layers: closely packed, un-uniform spiral configuration Secondary wall: mechanical and tensile strength	
Fibrils: all cellulosic Microfibrils: strong hydrogen bonds and van der Waals maintaining configuration	High microfibril angles (MFA) and high cellulose content: give moderate strength but low extension	Cellulose microfibril crystal lattice (Morton, 36)
	Staple fibre (6mm-65mm)	High crystallinity and water absorbency rate

Table 4.1: Cotton chemical properties[27]

[26] Note: for in-depth information on cotton's structure see: M. Ansell and L. Mwaikambo, "The Structure of Cotton and Other Plant Fibres," in *Handbook of Textile Fibre Structure, Volume 2: Natural, Regenerated, Inorganic and Specialist fibres,* ed. S. Eichhorn, 62-94, (Cambridge: Woodhead Publishing Ltd.) 2009.

[27] Table information compiled from: Ansell, 64-65 and 70-72, W. E. Morton and J. W. S. Hearle, *Physical Properties of Textile Fibres*, Fourth ed, (Cambridge: Woodhead Publishing Ltd.) 2008, 37-38.

4.2.2. Physical properties

Origin and manufacturing processes have considerable effect on cottons' properties as well as the fibres' staple length. Fibres can range from long and fine to short and coarse (6-65mm) with low to fairly high strength (less than 1.1-2.2 dtex). Decitex (dtex) is a yarn density measurement equaling grammes per 10,000 metres of yarn and Tex equaling grammes per one kilometre.[28] Yarns made of longer fibres tend to have higher strength, because more space allows the fibres to grip one another. Fibre fineness also determines strength, and the amount and uniformity of twist and yarn plies, where the more uniform and more plies produces higher strength.[29]

The fibre's dimensional stability produces low extension and elastic recovery. Extension can be as low as one percent if the yarn has undergone processes such as preshrinking. Its fairly high DP (degree of polymerisation; average number of monomers in a polymer) also accounts for higher tensile strengths.[30]

Mercerisation, a common treatment, uses caustic soda to remove impurities and swell the microfibrils. This lowers the DP and produces greater moisture absorbency, strength, and lustre.[31] [32]

Water saturated cotton is 10-30 times stronger than when dry, but this varies with aged fibres.[33] Cotton has good resistance to many degradation factors; photodegradation and microorganisms affect it most with strength loss.[34]

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[28] J. Gordon Cook, *Handbook of Textile Fibres: Vol. I. Natural Fibres*, (Oxford: Woodhead Publishing Limited) 2001, 49.

[29] Cook Vol. I, 65.

[30] Tímár-Balázsy, 20.

[31] Ansell, 79.

[32] Cook Vol I, 67-68.

[33] Ágnes Timár-Balázsy and Dinah Eastop, *Chemical Principles of Textile Conservation*, (Oxford: Butterworth-Heinemann) 1998, 33-34.

[34] Cook Vol. I, 69-70.

4.3. Silk

4.3.1. <u>Chemical make-up</u>

As shown in table 4.2, silk is a proteinaceous fibre derived from insects, generally the silkworm *Bombyx mori,*[35] which secretes silk fibres to form its cocoon.[36] Raw fibres consist of two long fibroin filaments bound together with sericin.[37] The sericin is generally removed after manufacture with high water temperatures.[38][39]

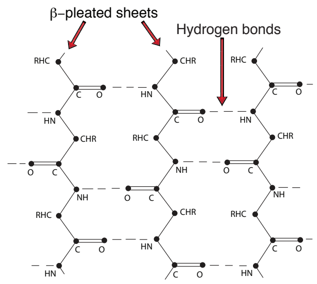
Chemistry	Fibre	Structure
Proteinaceous insect fibre Fibroin: protein filaments Sericin: binding gum protein (water soluble by hydroxyl groups)	Fibroin: linear filaments Sericin: mechanical protection during manufacturing	
Fibroin: Polypeptide chains (linear protein polymer chains) Carbon, hydrogen, nitrogen and oxygen	Pliable fibre: sheets can slip by each other due to van der Waals forces	Fibroin crystal structure with pleated configuration (Morton, 51)
Polypeptide chains: (crystalline regions) fully extended β-pleated sheets, strong hydrogen bonds and van der Waals forces hold formation		Crystalline regions: small amino acids, provide high mechanical strength and chemical resistance Amorphous regions: other amino acids and bulkier side groups

Table 4.2: Silk chemical properties[40]

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[35] Note: there are other sources of silk such as from spiders which result in different fibre properties but these will not be included in this research.

[36] Cook Vol. I, 144.

[37] Tímár-Balázsy, 43.

[38] Tímár-Balázsy, 43.

[39] Note: for in-depth information on silk's structure see: Cook Vol. I, 144-165.

[40] Table information compiled from: Tímár-Balázsy, 43 and Cook Vol. I, 164.

4.3.2. Physical properties

Raw silk has a stiff hand and dull appearance but generally better mechanical strength, while degummed silk is softer and lustrous.[41] Up to 25% of its weight is lost during the degumming process and is weaker and more susceptible to degradation factors.[42]

The extended β-sheets allow limited elongation. Elastic recovery is better than cotton but less than wool. If stretched beyond 2%, permanent deformation occurs with a slow, incomplete recovery. DP ranges from 300-3,000, reflected by the silk source and measurement methods, resulting in fair to good mechanical strength.[43]

Two common yarn types found in conservation are tram and organzine. Tram, a lightly twisted yarn with two or three twists (but as high as 12-20) per 25mm, is moderately strong and soft. Organzine, made from strong high quality silk, has two or more plies twisted separately and then twisted together in the opposite direction (about 9-30 twists per 25mm). Yarns with no twist are also common, while in the textile industry higher strength yarns are achieved with higher twists and more plies.[44]

At 40% RH, fibroin's water absorbency retains its flexibility, but may desiccate below 40% RH.[45] Silk is the most sensitive of natural fibres to photodegradation and fibroin is sensitive to thermal degradation.

4.4. Wool

4.4.1. Chemical make-up

Shown in table 4.3, wool is a proteinaceous hair fibre derived from the sheep's undercoat. It has one of the most complex fibre structures used for textiles.[46] The lipids, mainly lanolin on the outer cuticle, are mostly removed during manufacture.[47]

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[41] Cook Vol. I, 154-55.

[42] Tímár-Balázsy, 43-45.

[43] Tímár-Balázsy, 43-45.

[44] Cook Vol. I, 155-56.

[45] Tímár-Balázsy, 45.

[46] Note: for in-depth information about wool's fibre structure see: F-J Wortmann, "The Structure and Properties of Wool and Hair Fibres," in *Handbook of Textile Fibre Structure Vol. 2: Natural, Regenerated, Inorganic and Specialist Fibres,* ed. S. Eichhorn et. al, 108-145 (Cambridge: Woodhead Publishing Ltd., 2009).

[47] Wortmann, 116.

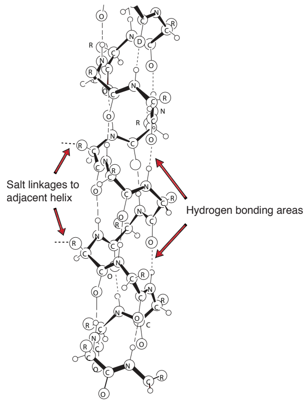
Chemistry	Fibre	Structure
Proteinaceous hair fibre Polypeptide proteins (97%) 24 amino acids Lipids (about 2%) About 1% mineral salts, nucleic acids and carbohydrates	Cuticle layers Cortex (about 90%) Medulla, inner hollow cavity (only in coarser wools)	
α-keratin protein structure: cystine amino acid, large sulphur content Carbon, hydrogen, oxygen and nitrogen	Cuticle: protective scales, frictional properties Exocuticle: cystine content (disulphide cross-links), mechanical and chemical protection	α-Helix configuration structure of polypeptides (Morton, 54)
Helix configuration: large side groups in protein chains twist and fold Internal structure: stabilised by secondary bonds, hydrogen bonds and salt-linkages, giving strength	Natural crimp	Crystalline (< 30%): three twisted protofibril helices, strong secondary bonds and salt linkages Amorphous regions: non-helical keratin matrix, large side groups, disulphide cross-links.

Table 4.3: Wool chemical properties[48]

4.4.2. Physical properties

Many factors affect wools' quality and properties such as the sheep breed, area on its body, environmental conditions where it lived, and fibre lengths (36-176mm range). Yarns can either be woollen or worsted. Woollen yarns are bulkier and held with a loose twist, while worsteds are finer, smoother, and stronger; generally made with higher twists. Shorter fibres require more twist to hold them in place than with longer fibres. However, a tighter twist

[48] Table information compiled from: Wortmann, 116, Morton, 56, and Tímár-Balázsy, 48-49.

generally makes a stronger yarn.[49] The natural crimp allows the twist to be held together. The amount of crimp also denotes quality, with higher crimp indicating higher quality.[50]

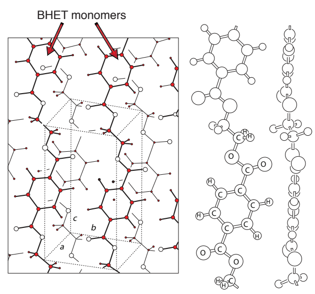
Wool has low resistance to elongation resulting in low tensile strength but high elongation properties.[51] Under 2-3% elongation the hydrogen bonds deform but almost 100% can be recovered. After further elongation, the amorphous disulphide linkages break turning the helices into fully extended β-keratin sheets like that in silk. Microfibrils uncoil and protofibrils change position in the last phase of elongation. However, with a higher RH, wools' good moisture absorbency allows more elongation. The fibres' natural crimp and twisted helix structures give high elasticity and allows it to recover after elongation.[52]

Wool is most sensitive to photodegradation, many alkaline solutions, insects and micro-organisms.[53]

4.5. Polyester

4.5.1. Chemical make-up

Shown in table 4.4, polyethylene terephthalate (PET), a common polyester, is a man-made synthetic polymer fibre. In conservation it is generally made from a continuous-filament, but staples are also used, then a multifilament yarn is held together with a slight twist.[54][55]

PET	Manufacture	Structure
Man-made synthetic polyester polymer Monomer: Bis-(2-hydroxyethyl) terephthalate (BHET)	Polycondensation: with ethylene glycol and terephthalic acid creating dimethyl terephthalate	

[49] Cook Vol. I, 92-97.

[50] Cook Vol. I, 102.

[51] Note: for further breakdown of the properties which effect tensile strength and elongation see: Morton, 597-603.

[52] Cook Vol. I, 104.

[53] Cook Vol. I, 107-08.

[54] Tímár-Balázsy, 56-57.

[55] Note: for in-depth information on PET's structure see: A. East, "The Structure of Polyester Fibres," in *Handbook of Textile Fibre Structure, Vol. 1: Fundamentals and Manufactured Polymer Fibres*, ed. S. Eichhorn, 181-231, (Cambridge: Woodhead Publishing Ltd, 2009).

PET	Manufacture	Structure
Polymer stabilisation from van der Waals forces	Polymerisation catalysts to form polymer: manufacture variations	Crystal structure viewed from side and above (Morton, 62)
Molecular weight variations: higher greater tenacity, lower less tenacity	Extrusion through spinneret creates single filament fibre	Degree of orientation variations: higher tenacity and crystallinity requires more stretching
	Heat-setting fibres stabilises and prevents shrinking	

Table 4.4: PET chemical properties[56]

4.5.2. Physical properties

PET yarns are generally produced in three types: a high tenacity filament, medium tenacity filament, and a staple yarn. These categories along with yarn tex determine most of the properties. Medium tenacity filaments are generally used in conservation, ranging from about 28 dtex to 167 dtex where individual plies are about 2.2 dtex. The more plies, the higher overall dtex.[57] Tensile properties are not greatly affected by moisture, however lack of moisture contributes to static charges.[58]

Because high tenacity fibres are stretched more in manufacture, they have less elongation, a higher modulus and greater resistance to stretching. Medium tenacity fibres have better elongation as stretching in manufacture is less. The weaker the PET fibre, the better their elongation. All have high deformation resistance and are stiff fibres with good elastic recovery, however less than wool, attributed to the manufacturing heat-setting process.[59]

Polyester has high resistance to degradation factors.[60] The degree of resistance is related to the crystallinity and molecular orientation manipulated during manufacture.[61]

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[56] Table information compiled from: East, 189-91 and 222-23, P. Santhana Gopala Krishnan and S. Kulkarni, "Polyester Resins," in *Polyesters and Polyamides*, ed. B. Deopura et al., 3-40, (Cambridge: Woodhead Publishing Ltd, 2008), 19, and J. Gordon Cook, *Handbook of Textile Fibres: Vol. II. Man-Made Fibres*, (Oxford: Woodhead Publishing Limited, 2001), 335-336.

[57] Cook Vol. II, 352.

[58] Cook Vol. II, 352-55, 364, 366.

[59] Cook Vol. II, 352-55, 364, 366.

[60] Tímár-Balázsy, 61.

[61] Santhana, 17.

4.6. Conclusion

The different properties of the fibres define their unique stress/strain curve shapes.[62] (table 4.5 and fig. 4.1).

Most, if not all, degradation processes will have an adverse effect on the physical properties of fibres. It is not possible to know exactly how each artefact's chemistry and physical properties have changed with time, but having a general understanding as to what and why they have degraded will allow conservators to choose the most appropriate threads for stitching treatments. Also, knowing the properties of the new materials conservators use and how they might change after treatments would inform the most appropriate decision.

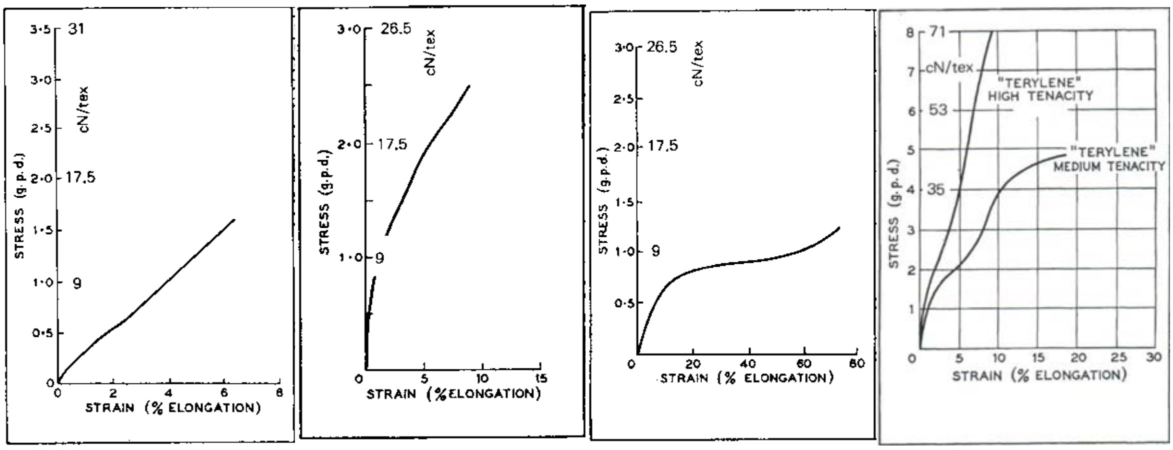
Properties	Cotton	Silk	Wool	Polyester (PET)
DP	11,000	300-3000	10,000-60,000	13,000-20,000
Crystallinity (%)	70	60	< 30	80-90
Moisture regain (%)	8.5	11	13.6-16	0.4-0.8
Tensile strength dry (cN/tex)	26.5-44.1	24.6-39.6	10.5-14.9	35.3-44.1
Elongation dry (%)	3-7	15-25	25-35	20-32
Elastic recovery at 3% extension (%)	75	90	99	90
Degradation resistance	Good resistance	Fair resistance	Fair to good resistance	Excellent resistance
Stress/strain curve shape	High modulus, straight	Fairly straight and high	Short modulus, long	Short initial modulus, double curve

Table 4.5: Comparison of fibres[63][64]

[62] Note: see section 5.2 for graph explanations.

[63] Note: values may vary by manufacture

[64] Information used in the table compiled from: Cook Vol I and II, Tímár-Balázsy, and Sara Kadolph and Anna Langford, *Textiles*, Ninth ed, (New Jersey: Prentice Hall, 2002), 26.



Cotton Silk Wool PET Polyester[65]

Figure 4.1: Typical tensile strength curves of the fibres

[65] Cook Vol. I, 71, 162, 109, and Cook Vol. II, 345.

5. Chapter 5. Tensile testing: experimental methodology

5.1. Introduction

The experimental methodology was carefully chosen in order to provide results that would best answer the research questions. In doing so, each aspect of the desired experiment had to be tested individually first. Though the desired final sample was to represent a conserved artefact sample using a stitched patch support, each component's bulk physical properties needed to be tested separately. Tensile strength testing was performed on the following:

- Stitching threads (single-strand method).

  Pretests:
  - Artefact samples, naturally aged fabrics (strip method).
  - New samples, representative of the artefact sample's fibre and weave types (strip method).
  - Conserved new samples, using the different threads couched onto a silk patch (strip method to break).
- Conserved artefact samples, prepared in the same way as above (strip method to 8 Newtons (N) to determine damage instead of break point).
- Conserved artefact samples (fixed-load method to determine damage over a period of time).

5.2. Strength and elongation test methods

Tensile strength testing is a method that measures the tensile properties of materials by applying a force.[66] These properties include strength (resistance to stretching) and elongation. Force is used to express length, time and mass in units of Newtons (N). One N is about equivalent to a small apple weighing about 100 grammes. The elongation determines the amount the material is resistant to force (in N) and how much the specimen stretches in millimetres. The relationship between the amount of load or stress to the amount of elongation or strain gives a graph recording known as a stress-strain or load-elongation curve (fig. 5.1).[67]

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[66] Note: for a more in-depth description of all aspects see: Morton, 274-321.

[67] B.P. Saville, *Physical Testing of Textiles*, (Cambridge: Woodhead Publishing Ltd, 1999), 115-116.

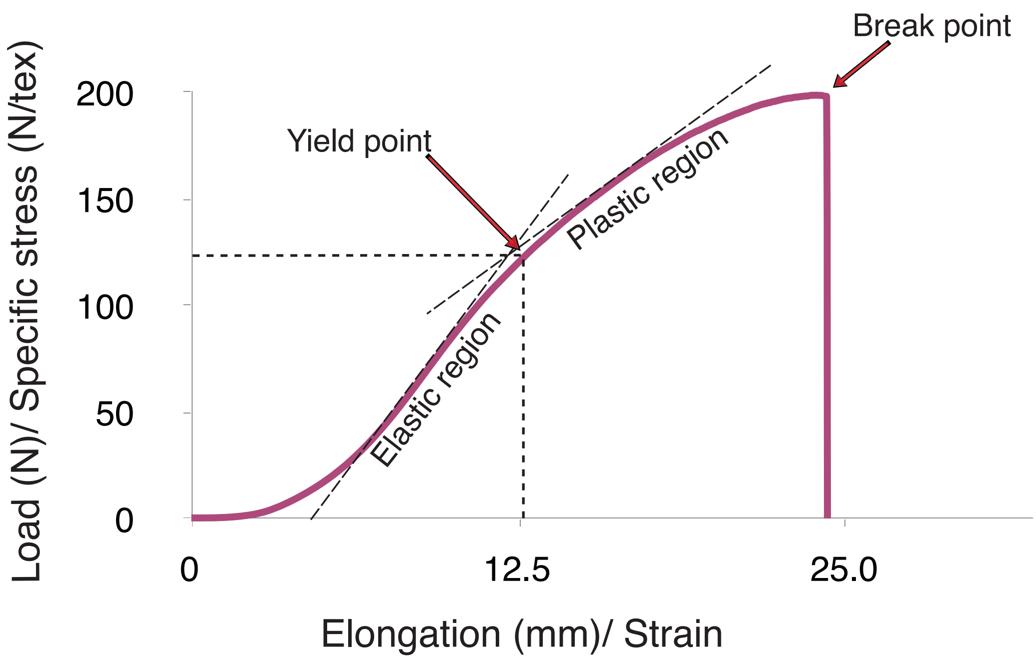

Figure 5.1: Load/elongation curve of silk fabric

Stress is used to determine the force that a material can withstand relative to its cross-sectional area. This calculation allows materials of various thicknesses to be directly compared, such as comparing the stress of a fine polyester fabric to the stress of a steel rod. Maximum stress is derived from maximum force by dividing it by the cross-sectional area of a fabric. However, to measure the cross-sectional area of a thread or yarn with accuracy is not possible. Therefore, the linear density of yarns are measured to give specific stress, or, more commonly, tenacity and generally measured in Tex as described in section 4.2.2.[68][69] Determining stress or specific stress for a material allows quantitative comparisons to be made with dissimilar materials or predict how a material might change when subjected to different situations.[70] Strain is an equivalent measurement for elongation but reported in different units where strain = elongation ÷ initial length.[71]

$$\text{stress} = \frac{\text{load}}{\text{area of cross-section}} \qquad \text{specific stress} = \frac{\text{load}}{\text{linear density}}$$

[68] Collier, 103.

[69] Saville, 77 and 116-18.

[70] Billie Collier and Helen Epps, *Textile Testing and Analysis,* (London: Prentice-Hall International, 1999), 98.

[71] Morton, 269.

There are three elements of the load-elongation[72] graph which give useful information about the bulk physical properties of the threads and fabrics. These are the modulus, yield point, and breaking point (fig. 5.1). The modulus is the initial area of the slope that is straight and indicates the material's initial resistance to extension with the applied force. This area denotes the stiffness of the material and is also referred to as the elastic region. The steeper the modulus slope, the stiffer and more resistant the material is to elongation. Cotton, for example, is a very stiff material exhibited by a very steep and straight modulus area with no yield point as explained in section 4.2 (fig. 5.2).[73] [74]

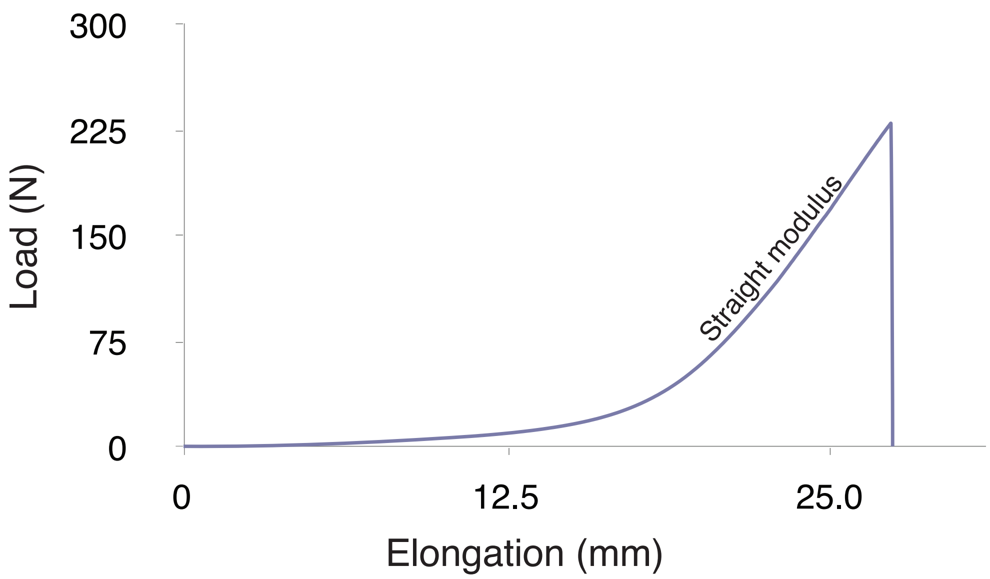

Figure 5.2: Load/elongation curve of cotton fabric

The yield point is the point on the curve when there is a marked decrease in the slope. This point marks the change from the elastic region to the plastic region (inelastic region). Within the elastic region before the yield point, the molecules of the material have not been permanently deformed and if the force were to be released a great degree of dimensional recovery would occur. However, after the yield point within the plastic region, the molecules have begun to slide past one another and have become permanently deformed. If the force is removed during this stage the fibres will not be able to recover and will remain in the deformed position. Not all materials have a yield point (such as cotton) and it is generally a small region rather than a direct point on the curve. There are several ways to determine

[72] Note: Load and elongation is an interchangeable terminology with force and extension with the only difference being in the units.

[73] Collier, 102.

[74] Saville, 123-125.

the yield point. For this research the Coplan's construction was used in which two lines are drawn, one in line with the flat modulus at the beginning of the curve and the other in line with the flat section of the plastic region; the perpendicular point at which they intersect and cross the curve is the yield point (fig. 5.1).[75][76]

The breaking point is the point at which the material breaks and/or is no longer able to withstand a load indicating the maximum force that can be applied. However, this point may not be direct and after the breaking point the curve may not immediately drop to zero. This is frequently the case with wool (fig. 5.3). In this case, maximum tensile force (the highest point on the curve) is used. When a material's elongation continues after this point it denotes that not all the molecules within the fibres break or rupture at the same time.

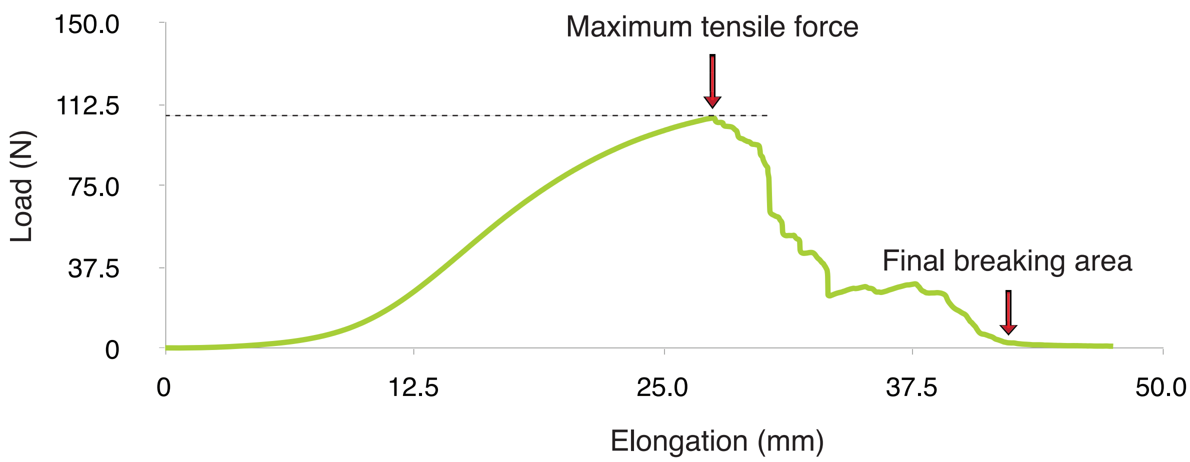

Figure 5.3: Load/elongation curve of wool fabric

There are many factors that affect the bulk properties of a fabric as introduced in Chapter 4. When testing a fabric it is important to account for the yarn type, twist and fineness because they all affect the strength of the overall fabric. Anything that contributes to frictional force within a yarn will increase its strength, such as higher degree of twist. An important difference is between filament fibres, which are stronger and experience fibre breaks, and staple fibres, where the frictional force and twist of the yarns means they will be pulled apart as well as experience fibre breaks. The weave type and count in fabric construction is most important in determining properties. Closely woven (high count) and balanced fabrics have higher strength than lower count and unbalanced weave types.[77]

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75 Collier, 103.

76 Saville, 119-123.

77 Collier, 106-08

5.2.1. Equipment used

An Instron 5544 Tensile Strength Tester with Bluehill software version 1.4 was used to perform all tensile strength testing. This equipment is a constant rate of extension (CRE) machine. It consists of two grips, where the lower grip remains in a fixed position and the upper grip moves upward exerting a force at a constant rate in order to stretch the specimen (fig. 5.4). The load cell, located in the upper grip of this model, measures the specimen's resistance to force. This and the moving grip are connected to the recorder that charts the load-elongation curve as the specimen is being tested. The accuracy of the load cell is dependent upon its upper limit, the higher the limit the lower the accuracy at the lower limit. Therefore, weaker yarns or fabrics will require a different load cell with a smaller upper limit.[78][79] Here load cells of 100N and 1kN were used for yarn and fabric respectively.

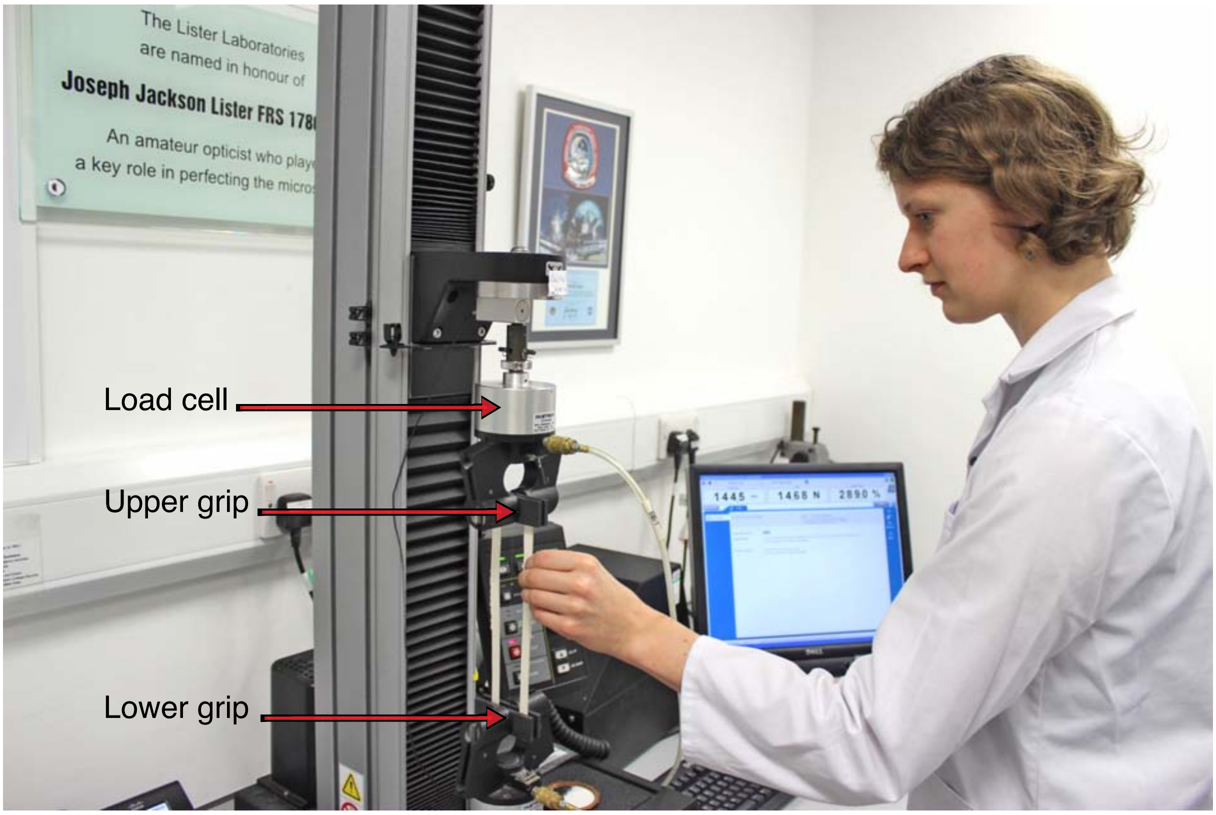

Figure 5.4: CRE tensile strength apparatus used

5.3. Test materials

5.3.1. Stitching threads

The following threads were chosen as representations of the most fine thread types currently available and in use in conservation:

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[78] Saville, 132-33.

[79] Collier, 108-10.

1. Fine lace cotton 185/2; manufactured in Egypt. ‘S’ high twist 2-ply, individual plies are staple, not mercerised (manufacturer stated as gassed cotton, un-dyed).
2. 2-ply hair silk; manufactured in France. ‘S’ loose twist 2-ply, individual plies are filament (appears raw sericin gum present, un-dyed).
3. Purchased spool silk thread, organsin; manufactured in France. ‘S’ medium twist 2-ply, individual filament plies (appears degummed, un-dyed).
4. Skala 360 polyester; manufactured in Spain. ‘Z’ high twist of multiple monofilaments (un-dyed).
5. Warp threads drawn from Tetex polyester fabric; manufactured in Switzerland. ‘S’ high twist 2-ply, individual filament plies (un-dyed).

(See table 5.1 and Appendix 9.3 for supplier information and Appendix 9.8 Material samples.)

Un-dyed new threads were chosen to give a clear starting point while controlling the number of variables such as dyestuff and ageing which were beyond the scope of this research.

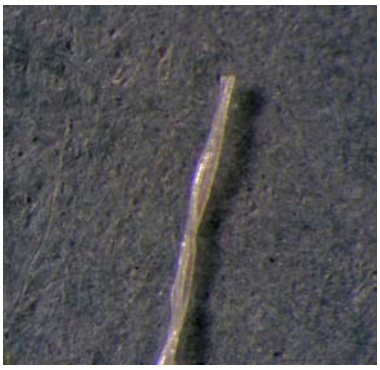
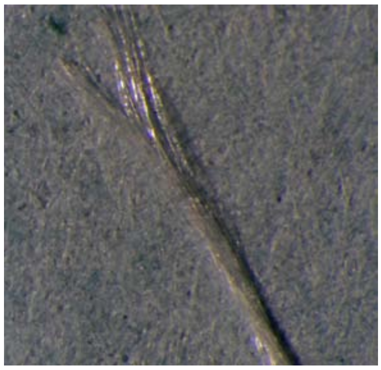
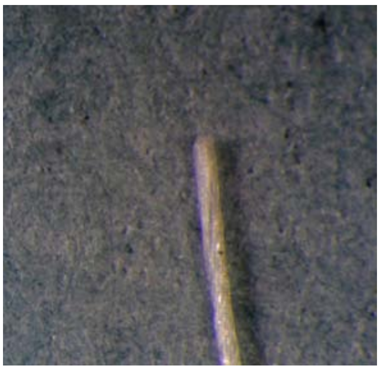
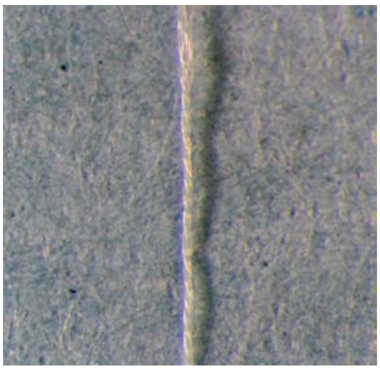
		
Lace cotton	Hair silk	Organsin
		
Skala	Tetex	

Table 5.1: Thread visual morphology

5.3.2. Artefact samples

The artefact sample fabrics were chosen to give a range of the natural fibre types most commonly seen in textile artefacts. All were naturally aged and had a limited amount of visual degradation. The main varieties of degradation seen on all samples were different forms of stains, loose particulates, light damage, and areas of structural weakness. The samples chosen were the most alike in structure that could be obtained (Appendix 9.8 Material samples). All analysis was confirmed by microscopy and the yarns were counted with the aid of a stereomicroscope and yarn pick.

- Cream coloured raw cotton christening gown, late 19th early 20th-century, fine plain weave (‘Z’ low twist 2-ply staples; average of 35 warps and 34 wefts per 10mm).
- Cream coloured silk scarf, late 19th early 20th-century, fine plain weave (low/no twist of single ply filaments; average of 57.33 warps and 34.33 wefts per 10mm).
- Pink coloured wool coat, 1960s-1970s, plain weave (worsted staple yarns, ‘S’ loose twist 2-ply; average of 16 warps and 16 wefts per 10mm).

See table 5.2 on following page.

5.3.3. New samples

To establish an appropriate range for the load applied in the tensile tester for each conserved artefact sample, samples using new fabrics were tested first. The fabrics chosen to replicate the artefact samples were:

- New un-dyed cotton lawn (‘Z’ low twist 2-ply staples with 43 warps and wefts per 10mm).
- New un-dyed silk medium weight habotai (low/no twist of single ply filaments with 56 warps and 39 wefts per 10mm).
- New un-dyed Voltaire fine wool (‘S’ medium twist worsted, 2-ply staple yarns with 14 warps and wefts per 10mm).

5.3.4. Support fabric

Medium weight silk habotai was chosen as it is a commonly used basic support fabric. Though it may not be the most appropriate support fabric for the cotton or wool artefacts, introducing other materials would have created too many variables for this research.

- New un-dyed silk medium weight habotai (low/no twist of single ply filaments with 56 warps and 39 wefts per 10mm).

	Cotton artefact sample
	
Silk artefact sample	Wool artefact sample

Table 5.2: Artefact sample pieces

5.4. Tensile testing: stitching threads

5.4.1. Aims

To obtain a comprehensive understanding of and allow for accurate comparison of the chosen threads' properties, initial testing was required. This experiment was conducted independently of other conservation variables like different artefacts and support fabrics. Information gathered was then used to hypothesis and understand how and why certain threads behave differently when stitched. This section of the experiment was based upon the work of Shirley Ellis.[80]

5.4.2. <u>Linear density of threads</u>

As the linear density (tex) of threads is required for some of the equations for tensile testing, the approximate tex was measured for all the threads to be tested. Linear density expressed in the Tex System relates the value density of a yarn in numerical units. e.g.1 tex= 1g/km= 10 dtex= 10dg/km.[81]

To determine the tex of the threads, one metre of thread was cut and weighed on a Sartorius BP150 d=0.001g scale. This gave the threads' weight to a decimal of 0.001, and multiplying this number by 1,000 gave the weight in grams per kilometre. The dtex of the Skala thread was provided on the spool and therefore was used first to check the method's accuracy. These values were then compared to Ellis' work which gave a comparison to different known threads in conservation and how manufacture may have changed in the last 15 years.[82] Through table 5.3 it was determined that the method used in this research was accurate, but not to the same decimal points as Ellis' work. Tetex is very similar in value and it can be determined its tex value has not been changed by the manufactures. However, the tex values for hair silk have decreased significantly, by over half, although this may also show that different sources or suppliers of hair silk provide threads of different qualities and tex values.

Thread type	Tex value	Threads tested by Ellis	Tex value (Ellis)
Lace cotton	6.0 tex; 60 dtex		
		Silk crepeline weft	1.66
Hair silk	4.5 tex; 45 dtex	Raw hair silk	9.09
		Degummed hair silk	8.04
Organsin	3.0 tex; 30 dtex		
Skala	8.0 tex; 80 dtex		
Tetex warp	2.0 tex; 20 dtex	Tetex weft	2.54

Table 5.3: Tex values of threads, all un-dyed

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80 Ellis.

81 British Standard, *Specification for a Universal System for Designating Linear Density of Textiles (Tex System)*, BS 947:1970 (London: BSI, 1999) 1.

82 Ellis, 13.

5.4.3. Test specimen preparation

BS 3411:1971[83] was used for guidance in the thread sample preparation. Each thread was prepared in the same manner. The tested length of each thread was 50mm. A card carrier was used to ensure the correct thread tension, placement and secure clamping by the tensile tester grips was achieved. The card was cut 90mm in length allowing 20mm at each end for the machine grips and giving a space for fixing the threads (fig. 5.5).

Five replicates of each thread type were prepared for testing to obtain a representative average.

As the testing room was not able to be controlled, the samples were preconditioned in a chamber for at least 48 hours at 55% RH ±10% at 21.5°C ±2°C.[84] These conditions were utilised to correlate with the standards for museum environments instead of the British Standards for 65% RH.[85]

5.4.4. Single-strand tensile testing

International Standard ISO 5079-1995[86] was used as a guideline for the testing procedure. The testing room's environment ranged from 33 to 34% RH and 28°C to 29°C over the course of two hours. The threads were taken from their preconditioned chamber into the test room in batches of five in a sealed container and only one was removed at a time for testing to maintain the RH of the samples at the conditioned level as much as possible.

A method using the Bluehill software was developed to accommodate the fineness of the threads being tested. The light load cell Instron Static Load Cell ±100 Newtons was used with an extension speed of 10mm per minute. All the individual thread's tex measurements were inserted into the formula before testing. The prepared specimens were mounted in the device by clamping the card at each end ensuring the thread remained perpendicular to the floor. Once the grips were clamped, the sides of the card were clipped in order to only test the thread (fig. 5.5).

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[83] BSI, *Method for the Determination of the Tensile Properties of Individual Textile Fibres,* BS 3411:1971 (London: BSI, 1971), 7, 10.

[84] The National Trust, *The National Trust Manual of Housekeeping: Care and Conservation of Collections in Historic Houses* (Swindon: The National Trust, 2011), 113.

[85] BS 3411:1971, 7.

[86] ISO, *Textiles-Fibres-Determination of Breaking Force and Elongation at Break of Individual Fibres*, BS EN ISO 5079:1996 (Brussels, London: 1995, 1999).

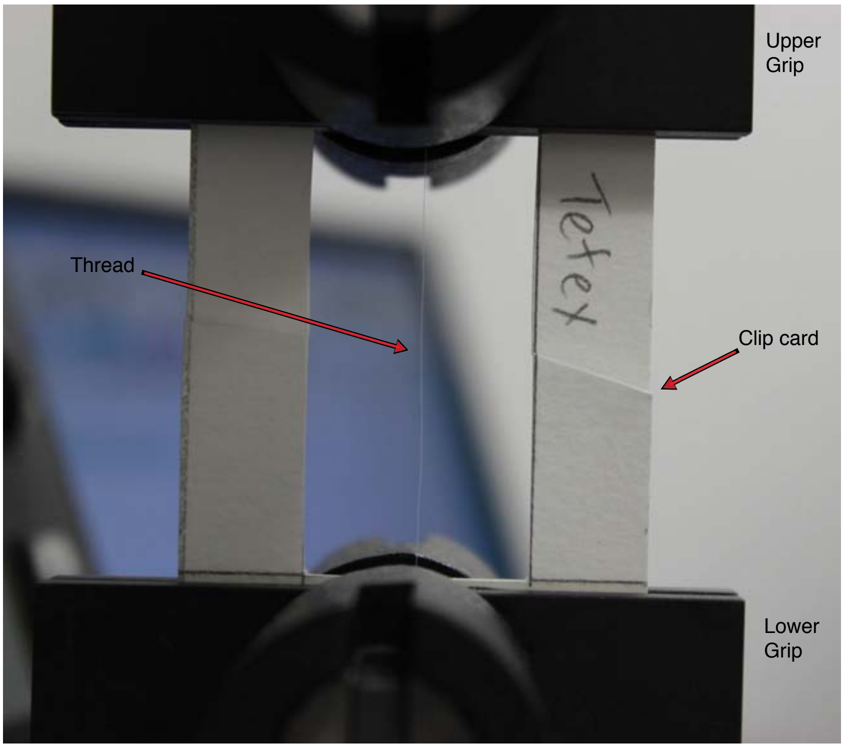

Figure 5.5: Layout of thread testing

5.5. Conserved samples preparation

5.5.1. Aims

To prepare the conserved samples for testing in a way that would provide consistent, accurate results while representing the real world situations found in textile conservation.

5.5.2. Test specimen preparation

BS EN ISO 13934-1:2013[87], BS EN ISO 13936-1and 2:2004[88], were consulted to inform and base the sampling and testing for this experiment.

Areas of extreme damage within the artefact samples were avoided as this would not be representative of the whole fabric, but areas of staining and general weakness were included as this is representative of an historic artefact. Due to fabric supply restraints, only the warp of the fabric was tested and having all different wefts in the samples could not be avoided. However, as the fabric was naturally aged and the objective of the testing was not to discover if the fabric itself was homogeneous, this was not deemed significant to this

[87] 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 13934-1:2013*, (London: BSI, 2013).

[88] International Organization for Standardization, *Textiles-Determination of the Slippage Resistance of Yarns at a Seam in Woven Fabrics, Part 1: Fixed Seam Opening Method, BS EN ISO 13936-1:2004*, (Brussels, London: 2004).

research (fig. 5.6). Five samples of each type of thread on each type of artefact fabric were prepared, making 25 samples cut from each artefact. The total cut sample size was 35mm wide including fringed area x 190mm including 25mm at each end for the grips. The fringe was required by the British Standards to ensure the same warps are tested throughout the specimen.[89] The final tested width after fringing was 25mm ±0.5mm. The length was determined by an area of 50mm on each end beyond the couching stitching, which was 40mm ±2mm (fig. 5.7). Before cutting, the cotton and silk artefacts were lightly pressed with a cool iron to ensure creases did not affect the test areas, the wool artefact was not creased.

Figure 5.6: Specimen layout guidelines on artefact samples

[89] BS EN ISO 13934-1:2013, 5.

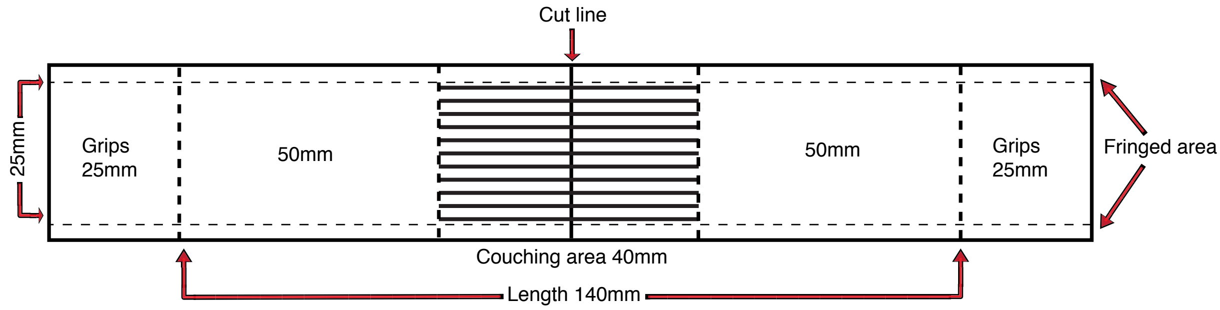

Figure 5.7: Template for specimen size

It was determined that cutting the sample in half would create stress at the stitch points. This would ensure the stitches and support fabric holding the cut together would be placed under force by the tensile testing, whereas if the artefact was only damaged, the strength of the artefact samples themselves would affect the results.

Stitching

The samples were prepared as identically as possible with the use of a Melinex® template to mark the stitching holes (fig. 5.8). The samples were prepared by more than one person, so written instructions were first given to each volunteer as it was desirable to minimise the number of variables in sample preparation ensuring more valid results. Five rows of couching stitches were placed across the sample at 6mm apart following the warp yarns of the artefact to hold the cut line together evenly. These rows were offset by 2mm at the ends so every other row was on the same weft line. All materials used were exactly the same. (See Appendix 9.4 Stitching instructions).

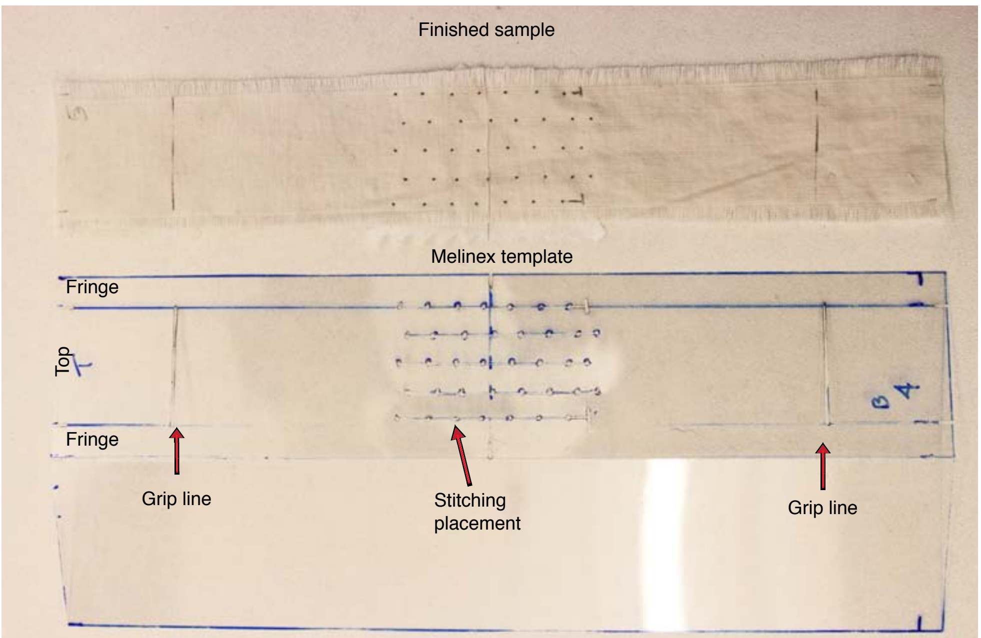

Figure 5.8: Template used for marking stitching lines

5.6. Tensile testing: pretests

5.6.1. Aims

In order for the conserved samples to be as valid as possible and to gain the best understanding of the materials involved, the fabrics needed to be tested without stitching and the conserved new samples needed to be tested to their breakpoint.

5.6.2. Artefact and new samples (strip method test)

All samples were preconditioned in the same manner as the threads tested in section 5.4. The environment throughout the testing ranged from 32%RH± 2% and 24°C± 1°C.

For the new samples and the artefact samples, three of each fabric was tensile tested to break. The same equipment was used as for the thread tests except for using a larger load cell: an Instron 2712-020 Static load cell with a maximum load of 1kN. The fabrics' thicknesses were required to achieve the correct calculations for stress. This measurement was taken using an Electronic Digital Micrometer 0-25mm with an accuracy of 0.001mm (table 5.4). This measurement would allow for the stress measurements of the different fabrics to be directly compared. The very limited amount of silk artefact only allowed the same warps to be tested as there was not enough fabric to stagger the placement horizontally, but this still provided a baseline for valid results. These tests also allowed for comparisons to be made between the new materials and the naturally aged artefacts to determine how much degradation may have occurred in the artefacts chosen. The testing of the un-conserved artefact samples allowed for the seam slippage of the conserved artefact samples to be measured (see section 5.7.2).

New fabric	Depth (mm)	Artefact fabric	Depth (mm)
Cotton	0.245	Cotton	0.230
Silk	0.125	Silk	0.100
Wool	0.655	Wool	0.800

Table 5.4: Depth measurements of fabrics

5.6.3. Conserved new samples (tested to breakpoint)

The conserved new samples were each tested to break; as there was only one of each sample, an average was not achieved. This test allowed for a better estimate of a beginning point of damage which indicated when to stop the tensile testing on the conserved artefact samples. This test also clearly showed whether the thread broke before the textile was irreversibly damaged. It should be noted these were new fabrics and should be more robust than most artefacts.

5.7. Tensile testing: conserved artefact samples

5.7.1. Aims

The desired outcome was to achieve results that would be comparable to situations found in textile conservation based on the relationship between the stitching thread, artefact, and support fabric. The aim was to establish the initial point of damage, as opposed to the breaking point, because artefacts rarely, and should never, experience forces strong enough to cause any full break in either the artefact, thread, or support.

5.7.2. Tensile testing

All samples were preconditioned in the same manner as the threads in section 5.4.

The testing method for the stitched artefact samples was decided upon using BS EN ISO 13936-1:2004 for the determination of slippage resistance of yarns at a seam in woven fabrics as a guideline. This method was chosen to give a numerical value to the change a couched conservation treatment makes to an artefact as a whole when compared to the unstitched artefact. It uses the load/elongation graphs of both a sample with no seam and a sample with a seam superimposed on top of each other. This allows the measurement of the elongation change seen within a sample containing a seam (or conserved cut in this case). As this test stops before the break point, it was also the most appropriate method to use to determine the point of damage.

This method stops the test at a force of 200N assuming specimens tested would be stronger than this load. The goal is not to break the seam, but to determine how much the seam separates the yarns in the fabric.[90] In a museum setting, however, an artefact would not be subjected to this much force and would break before reaching a 200N load. After testing the first part of test group 1 and evaluating the conserved new samples tested to break results, it was determined that only 8N of force was needed for the conserved artefact samples to incur their first damage. This load should represent a point where damage to any one of the components (artefact, thread, or patch material) has occurred (fig. 5.9).

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[90] Saville, 163.

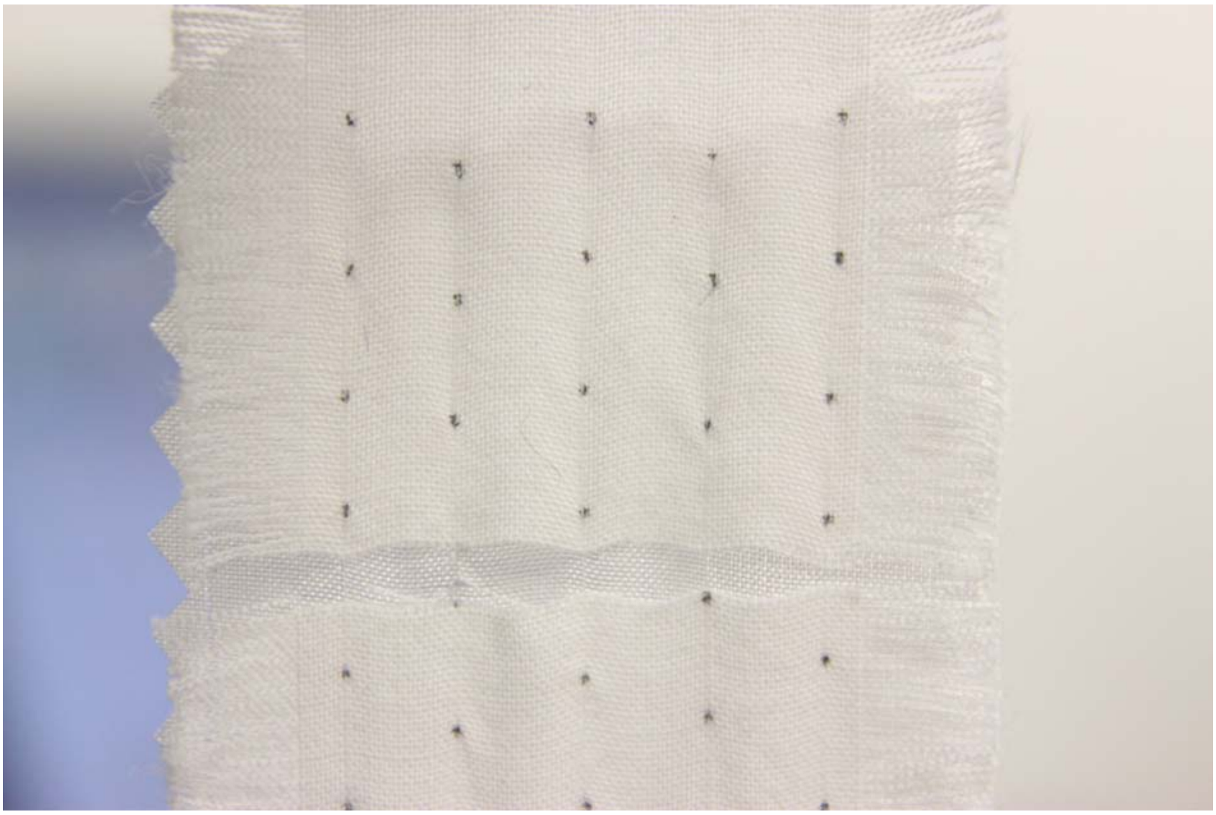

Figure 5.9: New cotton with Tetex about 10N, damage observed to weave and at stitch holes

Test group 1	Test group 2	Test group 3
Cotton with lace cotton	Silk with lace cotton	Wool with lace cotton
Cotton with hair silk	Silk with hair silk	Wool with hair silk
Cotton with organsin	Silk with organsin	Wool with organsin
Cotton with Skala	Silk with Skala	Wool with Skala
Cotton with Tetex	Silk with Tetex	Wool with Tetex

Table 5.5: Test groups, all on artefact samples

5.7.3. <u>Test group 1</u>

The cotton artefact base with each thread type was tested with four replicates, and the acquired results were used to calculate an average and standard deviation (SD). All samples were tested to 8N except for several samples from the conserved cotton with lace cotton, hair silk and organsin as the methodology was still being developed. The test was performed at a speed of 10mm/min to allow photos of the various stages. Once the apparatus reached 8N the test was stopped automatically, but manually returned to the beginning position to allow photographs to be taken of the samples.

The environment in the test lab varied from 50%RH± 1% and 24°C ±1°C.

5.7.4. Test group 2

The silk artefact base with each thread type was also tested with four replicates. All samples were tested to 8N and done in the same manner as test group 1.

The environment in the test lab varied from 33%RH± 1% and 24°C ±1°C.

5.7.5. Test group 3

The wool artefact base with each thread type was tested in the same manner as test group 1 and 2.

The environment in the test lab varied from 32%RH± 1% and 24°C ±1°C.

5.8. Fixed-load test: conserved artefact samples

5.8.1. Aims

As the scope of this research only tested new, un-dyed threads on natural fibre artefact samples, it was desired to create a test that could be easily reproducible in any lab so that conservators could test their own threads. This fixed-load method would also represent a more realistic comparison to the amount of force a textile artefact may be under in museum situations as well as introduce the aspect of time dependence. This method was inspired by Sheila Landi's work in 1988.[91]

5.8.2. Test specimen preparation

The specimens were first prepared in the same manner as described in section 5.5. An appropriate testing area was found in which to suspend the samples; a magnetic notice board. The board was a closable case which would ensure the experiment would be undisturbed throughout the testing.

First, one of each conserved artefact sample was attached to the notice board with a large straight magnet, level with the grip mark (25mm from the ends) to ensure even pressure, and then reinforced with stronger magnets above. Lead shot weights were prepared in plastic sample bags attached to a bulldog clip by a paper clip and Tyvek® tape. The total weight including the clips and tape was 50g. This was a considerable reduction from the 200g used in Landi's work[92] but following tests, 100g was deemed too heavy. 50g is comparable to half a cooking apple and this may be a realistic comparison to different types of weights textiles are subjected to while on display, such as textiles with heavier

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[91] Landi, "The Arguments For and Against the Use of Synthetic Fibres for Sewing in Textile Conservation."

[92] Landi, "The Arguments For and Against the Use of Synthetic Fibres for Sewing in Textile Conservation," 3.

embellishments or the textile's own weight. The weights were clipped to the bottom of each sample and before and after initial loading photographs were taken (fig. 5.10).

The environment within the case was monitored throughout, but it was too shallow to achieve desirable exhibition standards. The levels throughout testing ranged from 17%-51% RH and 20.2 to 22.8°C. Although these levels are extreme and undesirable for exhibited textiles, the materials used had been within the studio's uncontrolled environment for a long enough time to be at equilibrium with the ambient conditions of the studio. It is also useful to consider the uncontrolled environments as many exhibiting spaces are unable to control their environments to the recommended standards.

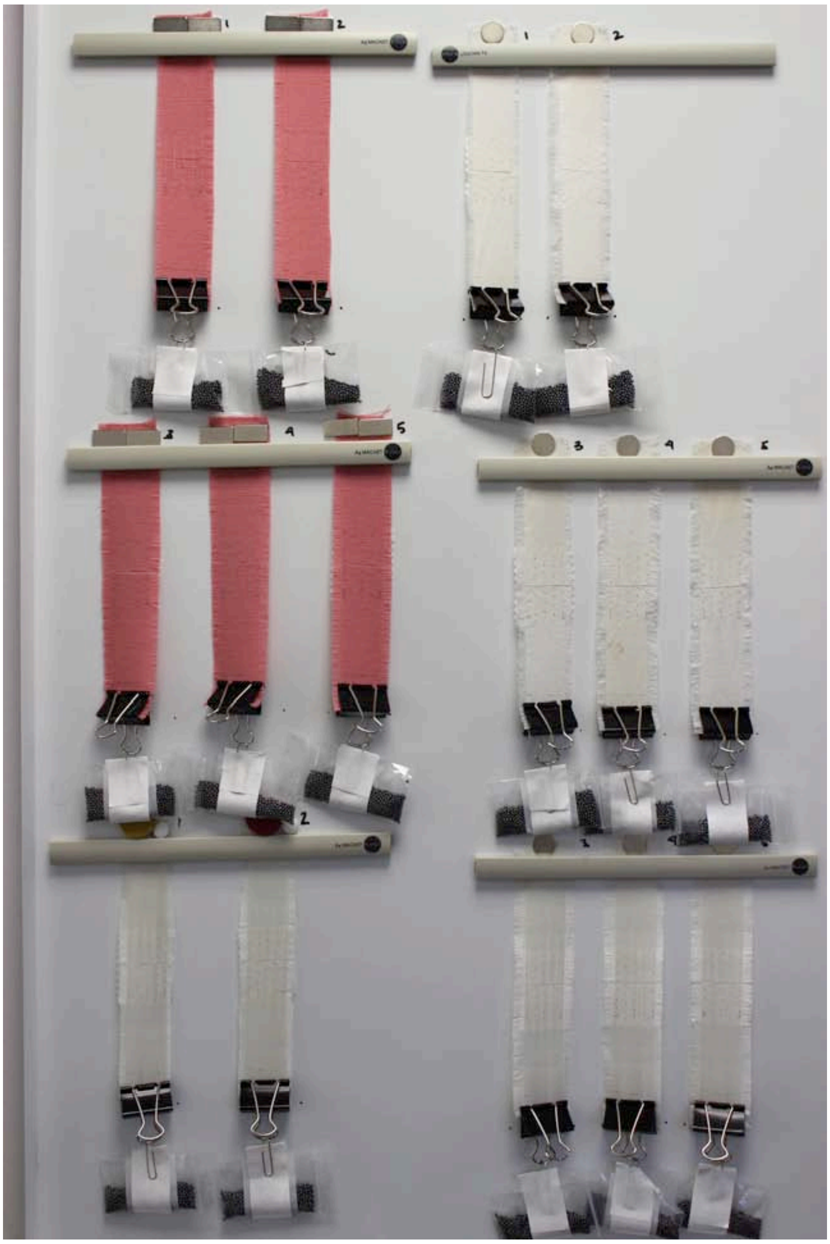

Figure 5.10: Fixed-load setup

5.8.3. Fixed-load test

The experiment lasted for two weeks with in-progress photographs taken about every three days. After which photographs and measurements of the artefact's initial recovery were taken. Measurements of the changes were calculated and analysed using Adobe Illustrator.

5.9. Summary of variables

The different artefact types chosen had many variables as they represented historic artefacts and not newly manufactured textiles.

Within the three different artefact materials and the five different threads, the variables of different specimens accounted to fifteen. However, many variables were uncontrollable and must be mentioned as unknowns (table 5.6).

Artefact material	Thread material	Testing variables
Various ageing patterns	Exact manufacture process unknown	Uncontrollable conditions, temperature and RH
Date of production unknown	Where original fibres sourced from unknown	Time element, preconditioning variations
Plain weave structures are not all the same	Exact manufacture date unknown	Amount of slack given to specimens at testing start
Manufacture processes unknown; finishes, colorants, etc.		First test group not all tested to 8N
The life of the artefacts unknown; washing, wear, etc.		

Table 5.6: Summary of unknown variables

5.10. Evaluation methods

5.10.1. Analysis before testing

Images were taken of a sample from each test group before any testing was done in order to give a visual comparison of how the testing affects all the different components. A Canon EOS 600D SLR camera with 18-55mm IS II lens was used for all the photography of the samples. Where close-up images were desired an Alpha Digital macro close-up lens was added to the camera. This magnification level would give a baseline for changes occurring within the weave structure. High magnification was carried out with a Dino Lite Premier digital microscope at 200x and 500x magnification to give a representation of what might occur at a the yarn level. A select number of samples were chosen for SEM photography with a Zeiss Gemini, Σigma VP Oxford instruments X-Max (Silicon Drift Detector) using the software programme SmartSEM to make observations of what occurs at the yarn and fibre level with very high definition (fig. 5.11). Only three SEM samples could be taken and the choice of samples was based upon a prediction of which thread might cause more damage, and which thread might cause little damage. Skala thread stitched on silk and wool, and lace cotton stitched on cotton were chosen to represent the use of a synthetics thread with a natural fibre artefact and a 'like-with-like' combination.

SEM was done in the VPSE G3 mode which allows the samples to be uncoated and shows the morphology by using the secondary electrons of a material differentiating elemental compositions (the higher the atomic number the brighter the reflection, so metals show brighter than carbon based materials).[93]

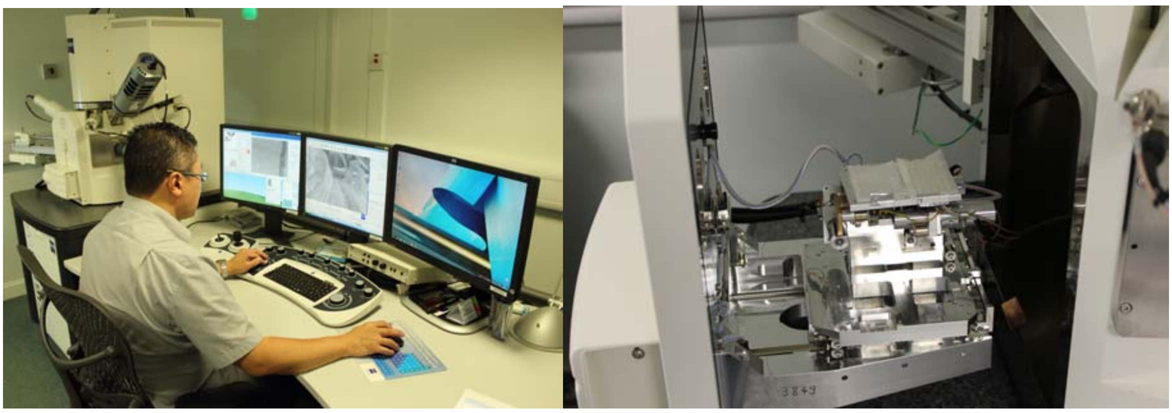

Figure 5.11: SEM setup and placing samples in the machine

5.10.2. Analysis after testing

High magnification photography

One of each test group variable was evaluated under high magnification using a Zeiss Stemi SV11 stereomicroscope. Photographs were taken using a digital camera with a lens small enough to focus through the eyepiece. This technique allowed immediate observations as well as later evaluation and comparison of the photographs to distinguish which samples and groups had more damage than others. This technique was also preferred over the Dino-Lite as it had higher resolution and more control over the magnification settings.

[93] Information gathered from personal communication with Peter Chung, ISAAC who performed the analysis.

SEM analysis

SEM analysis after testing was performed in the same manner using the same samples as described in section 5.10.1. However, the cotton artefact with lace cotton thread was a sample that only received 5.5N as opposed to 8N. An additional sample of cotton with Tetex was evaluated as it appeared to have a higher level of damage compared to other samples.

5.10.3. Statistical analysis

Statistics were performed using Microsoft Excel and the Bluehill software. From each test, a specimen that represented the approximate average of the group was chosen and added to a graph displaying the different samples. These included one of each thread type, one of each new sample, one of each artefact sample, the conserved new samples to break, and one of each conserved artefact samples to 8N. The conserved artefact samples were also added to a graph of one unstitched artefact sample in order to calculate the seam slippage/elongation. This was done using Adobe Illustrator and the RAW data from Bluehill software.

Histograms were made using Excel to compare the separate groups to each other based on total load, elongation, and stress (or thread tenacity) to determine any significant differences.

To determine the validity of the results, the SD of each group was calculated by the Bluehill software and inserted on the histograms using Excel. SD shows how much variation (plus or minus) is seen within a set of tests. If each data set has results placed close to the mean or average of the set, the SD is fairly low and the material would be considered homogeneous or uniform in structure. If the data set is more spread out from the mean and the SD is higher, the material is considered heterogeneous or dissimilar within its own structure and the results are less reproducible.[94] Aged materials will have more heterogeneous results as a material cannot age uniformly.

Further statistical analysis was not deemed necessary at the time. However, the raw data can be reanalysed if more information is required to compare to new research.

5.11. Conclusion

The tensile testing technique is very useful for conservators to determine which materials are best suited for conservation treatments as different levels of tensile properties are desired for different treatments. For example, a very strong thread with low elongation properties may be undesirable for stitching a fine textile, but may be the best choice when stitching a large heavy textile to a support for hanging exhibition.

[94] Rand Wilcox, *Basic Statistics: Understanding Conventional Methods and Modern Insights,* (Oxford: Oxford University Press, 2009), 76.

6. Chapter 6. Results

6.1. Aims

This chapter discusses the results of the tests performed and relates the findings for the materials tested to their role in textile conservation. Additionally, the results showed how these material properties may affect treatments in which they are used. (Appendix 9.5 for full tensile testing results).

6.2. Single-strand tensile testing

6.2.1. Data

Figure 6.1 shows the load versus elongation graph of the five different threads tested to break. The threads exhibited some very different properties. The extremes were Skala, which was able to withstand the largest load and had a steeper curve and Tetex, which had the greatest elongation with the least resistance to a load, resulting in a very long flat curve. Lace cotton had the highest resistance to a load with the least amount of elongation (as its modulus area was the steepest), while hair silk and organsin were in the middle. Implications and individual evaluation are discussed in section 6.2.3.

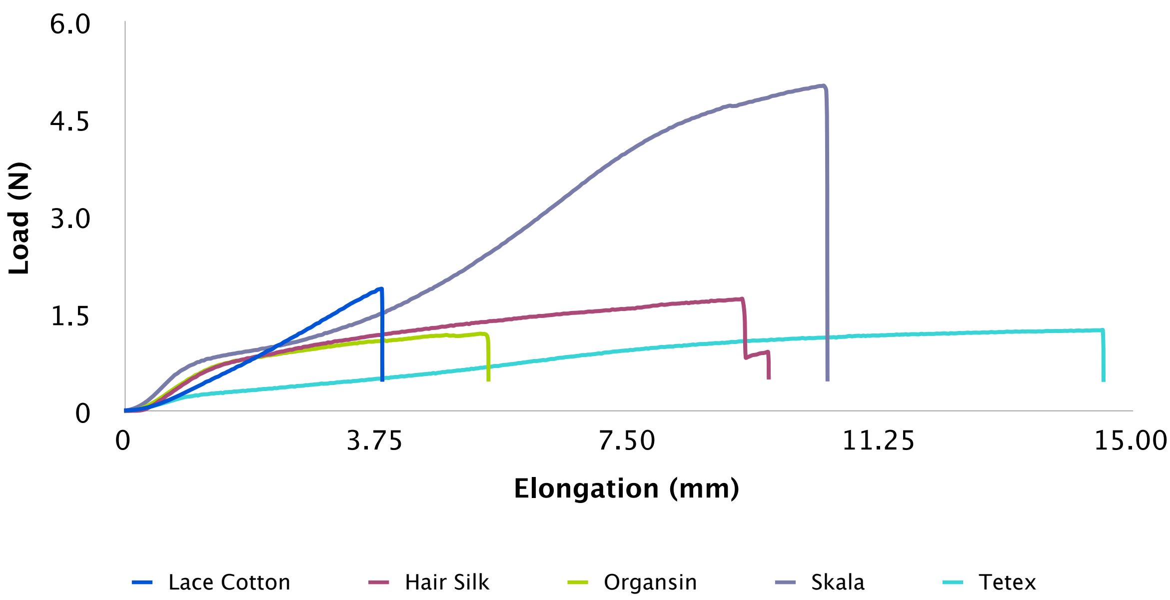

Figure 6.1: Load/elongation curves of all tested threads

6.2.2. Statistical analysis

The SD within each thread group tested used numerical data to objectively assess the results' validity and reproducibility.

SD for load, elongation and tenacity of each thread results were below 0.05 with the exceptions of: lace cotton, hair silk and Skala's load and elongation, and organsin and Tetex's elongation. However, each set of tenacity results gave very low SD results (below 0.01 cN/tex). Therefore, each set of materials were homogeneous and the results are reproducible.

Histograms showing SD within the maximum load, maximum elongation and tenacity are below (figs 6.2, 6.3, & 6.4). SD is shown by the error bar at the top of each bar. The longer the error bar, the greater the SD indicating greater variations between replicates. If any two of the bars have overlapping error bars, then they are not significantly different from each other in that aspect. For example, the SD error bar on organsin for maximum elongation is fairly long and overlaps the SD error bar of lace cotton (fig. 6.3). Therefore these two threads did not have significantly different maximum elongations. Whereas organsin's SD error bar does not overlap hair silk, Skala or Tetex and therefore had a significantly different maximum elongation to these threads (fig. 6.3).

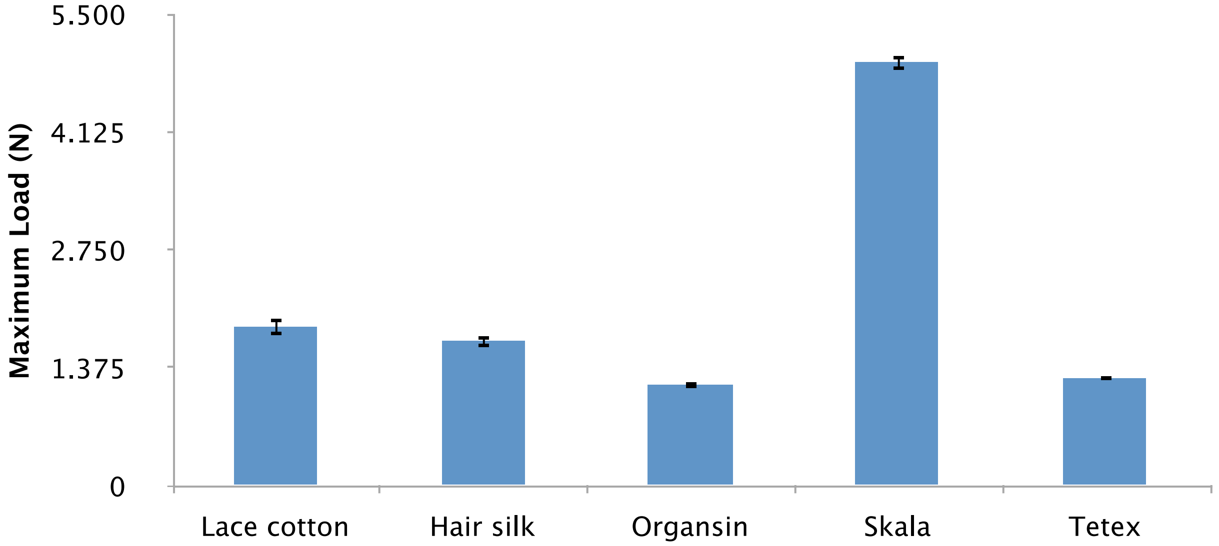

Figure 6.2: Maximum load reached by threads

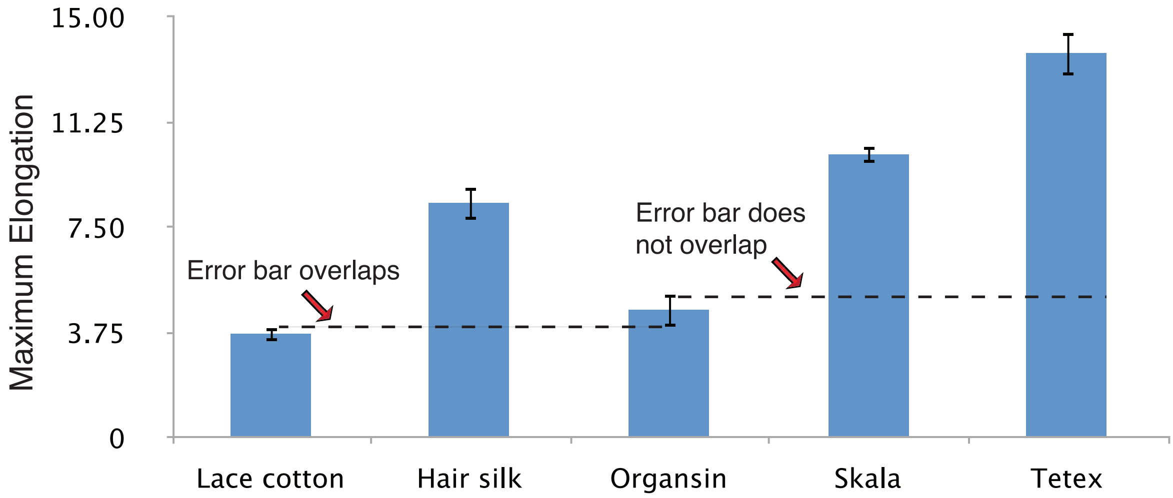

Figure 6.3: Maximum elongation reached by threads

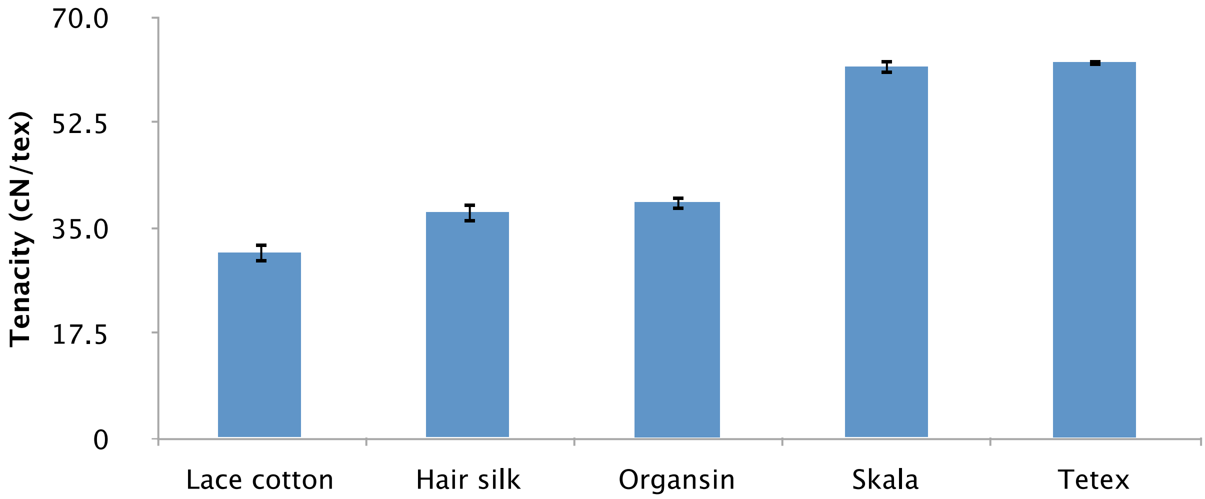

Figure 6.4: Tenacity of threads

6.2.3. <u>Results and discussion</u>

A breakdown of the graphs and histograms above gives a good comparison of the different threads' bulk properties. Within the individual thread graphs, the yield points and curve shapes can explain the various properties. The results gained in this test correspond to previous tests as seen in Chapter 4.

Lace cotton thread

Lace cotton exhibited the typical cotton graph with a high modulus and no yield point. High strength versus low elongation resulted in lower tenacity. If this thread was placed under a sudden, high stress, it would break completely instead of stretching with the load. In comparison to the other threads' SD, it was not significantly different from hair silk in maximum load or organsin in maximum elongation. However, its tenacity was significantly the lowest of the threads tested.

Hair silk thread

Hair silk displayed the typical high modulus before the yield point indicating fairly good elastic recovery. However, the inelastic range before the break point was quite long compared to other silk graphs (see fig. 4.1 pp. 32 and fig. 6.5). The presence of sericin gum may be an explanation. Perhaps after dyeing and the sericins' removal, the elongation would decrease. This is probable because sericin gum protects the inner fibre, allowing it to stretch further before breaking. An interesting observation on yarn structure was that the thread did not tend to break at once, but one ply at a time (fig. 6.6). As stated above, hair silk was not significantly different in maximum load to that of lace cotton, however, it was significantly different from all the other threads in elongation and had values in between the other threads'. The tenacity histogram revealed that although the hair silk and organsin had different overall properties, when linear density was taken into account with tenacity, it proved they were made of the same material (silk) because their tenacities were not significantly different (fig. 6.4).

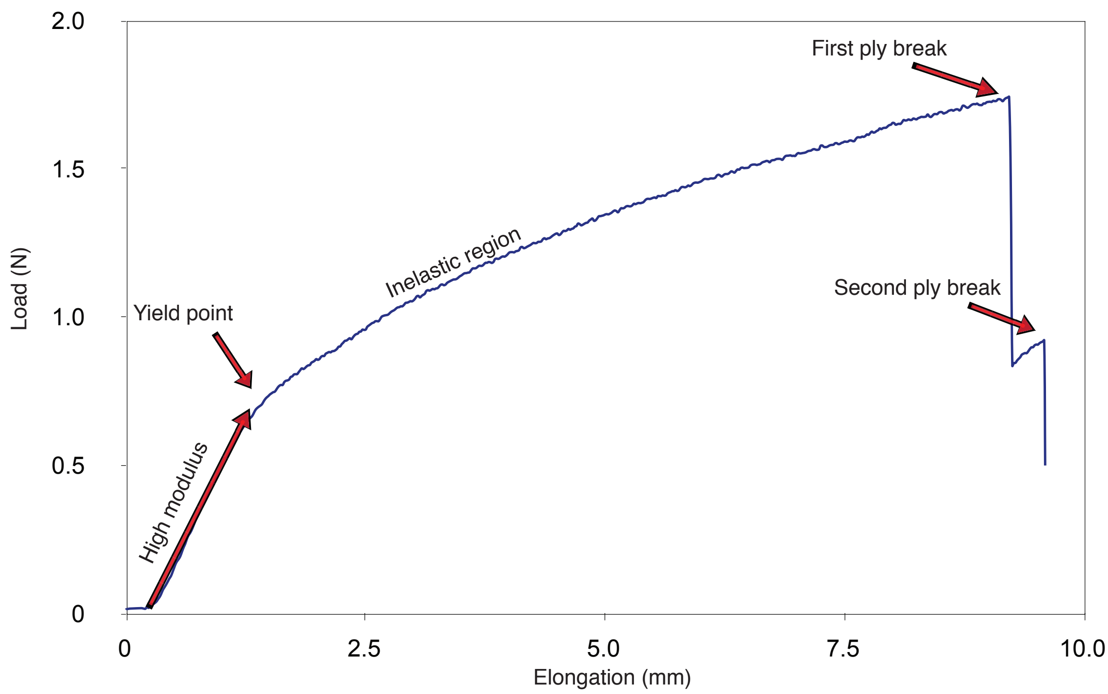

Figure 6.5: Hair silk load/elongation curve

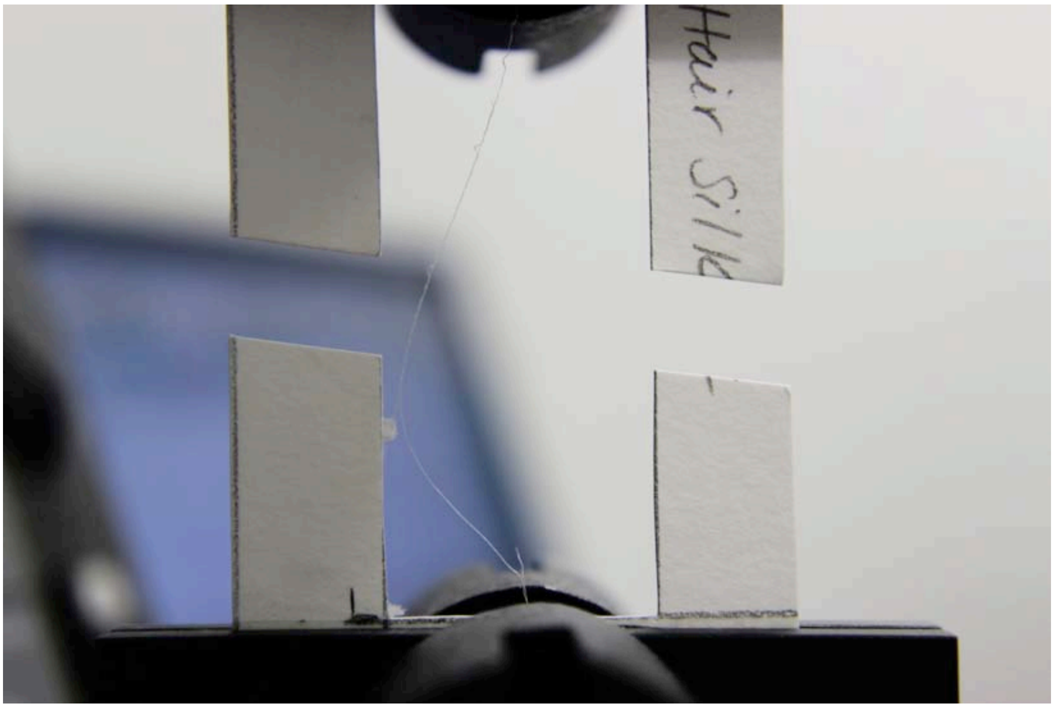

Figure 6.6: Hair silk at breakpoint

Organsin thread

Organsin had a very similar curve shape to the hair silk as they were both made of the same material, however, the shorter inelastic region resulted in a much lower maximum elongation (fig. 6.7). The lower maximum load and elongation may be attributed to the absence of sericin gum and although this produced a softer more lustrous quality compared to the hair silk, it was a weaker overall product. The SD between organsin's maximum load and that of Tetex was not significantly different, though Tetex had a much higher maximum elongation. Therefore, organsin can withstand the same amount of load, but breaks before Tetex as it cannot withstand the load for as long. Of all the threads, organsin had the lowest combined maximum load and elongation and may be regarded as the overall weakest thread. This was also revealed by the thread at break: it did not have a complete break or one ply breaking before the other, but the plies all broke/failed at the same time (fig. 6.8).

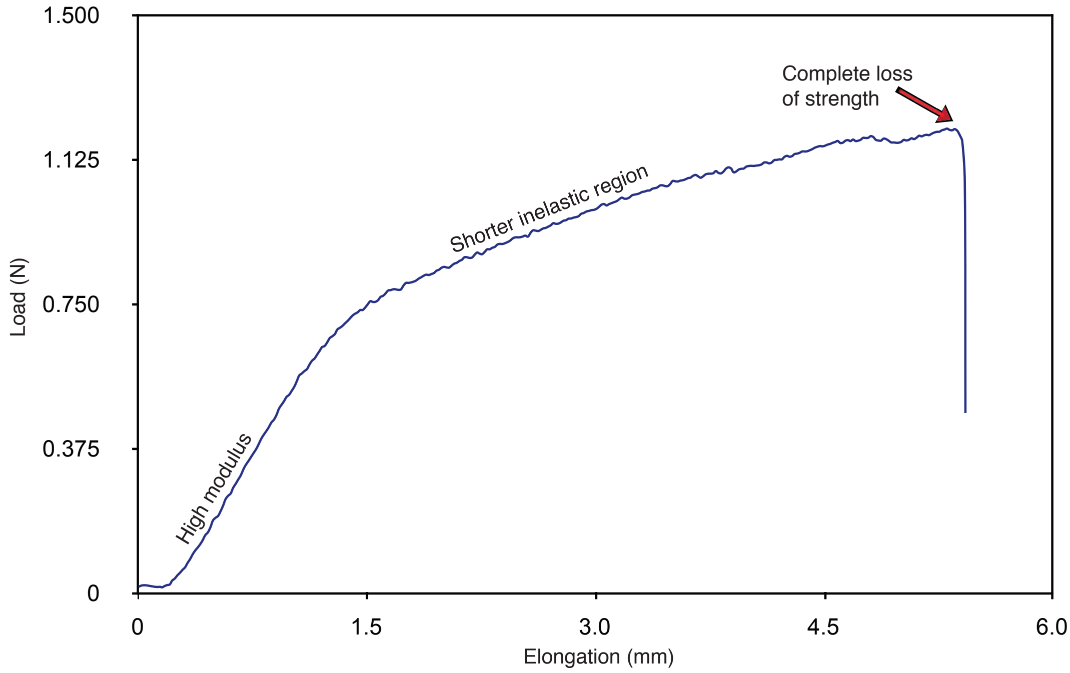

Figure 6.7: Organsin load/elongation curve

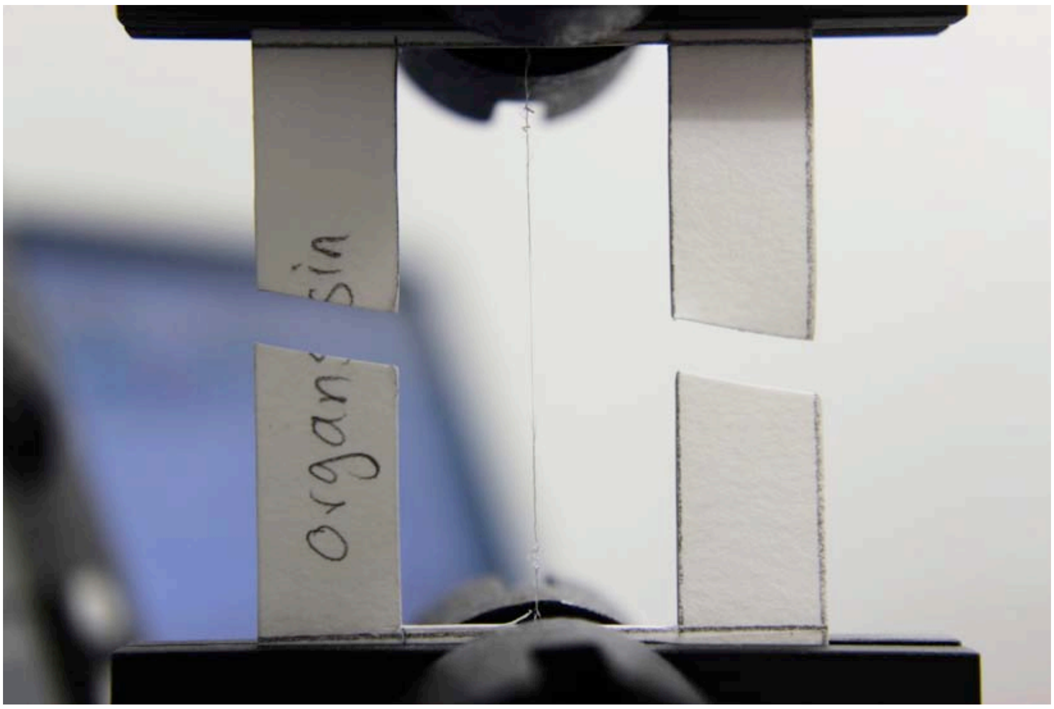

Figure 6.8: Organsin at breakpoint

Skala and Tetex threads

As Skala and Tetex are both made of polyester, the difference lay in their linear densities. This was seen in that their graph curves were similar in shape when viewed side by side and corresponded with the graphs of medium tenacity PET polyester (fig. 6.9 and fig. 4.1 pp 32).

Both exhibited a short modulus elastic region and a very long two part inelastic region. After the yield point, the curve was concave indicating less resistance to the load and was more easily stretched. Nearer the end of the curve it became convex indicating the material was becoming more resistant to elongation as the molecules became more aligned with less space to extend (fig. 6.9). Even though the materials displayed fairly high maximum elongations, the yield points were very close to the curves' beginning and therefore, though the materials could continue to extend, after this point they would not be able to recover and were permanently damaged. Skala had the highest maximum load, but was not significantly different from hair silk in elongation. Similar to the tenacities of hair silk and organsin, the tenacities of Skala and Tetex were not significantly different to each other, proving they were of the same material (PET) and their different elongation and loads were due to different linear densities. Both threads had complete break of all filaments at the same time. After break they were much more distorted than the other three threads tested, with the thread coiling back upon itself.

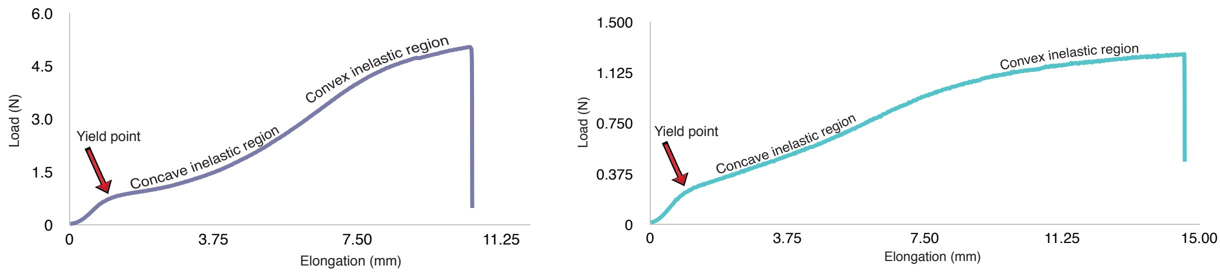

Figure 6.9: Skala and Tetex load/elongation curves

6.3. Tensile testing: pretests

6.3.1. Artefact and new samples (strip method test)

The artefact and new samples results are seen in fig. 6.10 below as well as the SD histograms in fig. 6.11. The individual properties of the fabrics were related to the results of the conserved samples in section 6.3.2 and 6.4.

Seen in fig. 6.10, the curves were similar in shape by material (e.g., new cotton to artefact cotton), but smaller when aged, with the exception of the wool. The curve shapes also related well with previous studies and the discussion in Chapter 4. However, the aged wool was much stronger with greater elongation than the new wool; see explanation with fig. 6.12.

The graphs and histograms showed that the aged cotton had the greatest loss of strength and physical properties compared with new cotton. While the silk had significantly lost strength, the overall stress (seen in the last histogram fig. 6.11), of its material makeup (silk fibres) had not significantly changed by degradation. Therefore, the cotton's chemical structure had degraded to a point where the material changed resulting in a heterogenous material. While the silk base material had also degraded to a heterogenous state, the chemical makeup remained more intact. The wool may be considered an anomaly, as the performance of the aged sample was superior in all aspects to that of the new wool indicating that although upon initial observation they seemed similar, they were in fact very different.

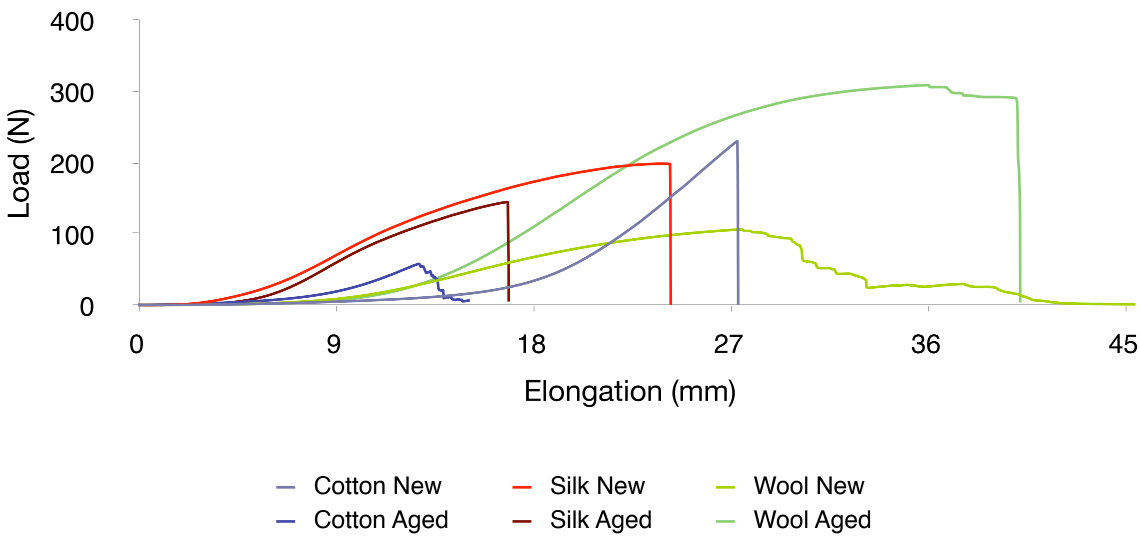

Figure 6.10: New and aged fabrics load/elongation curves

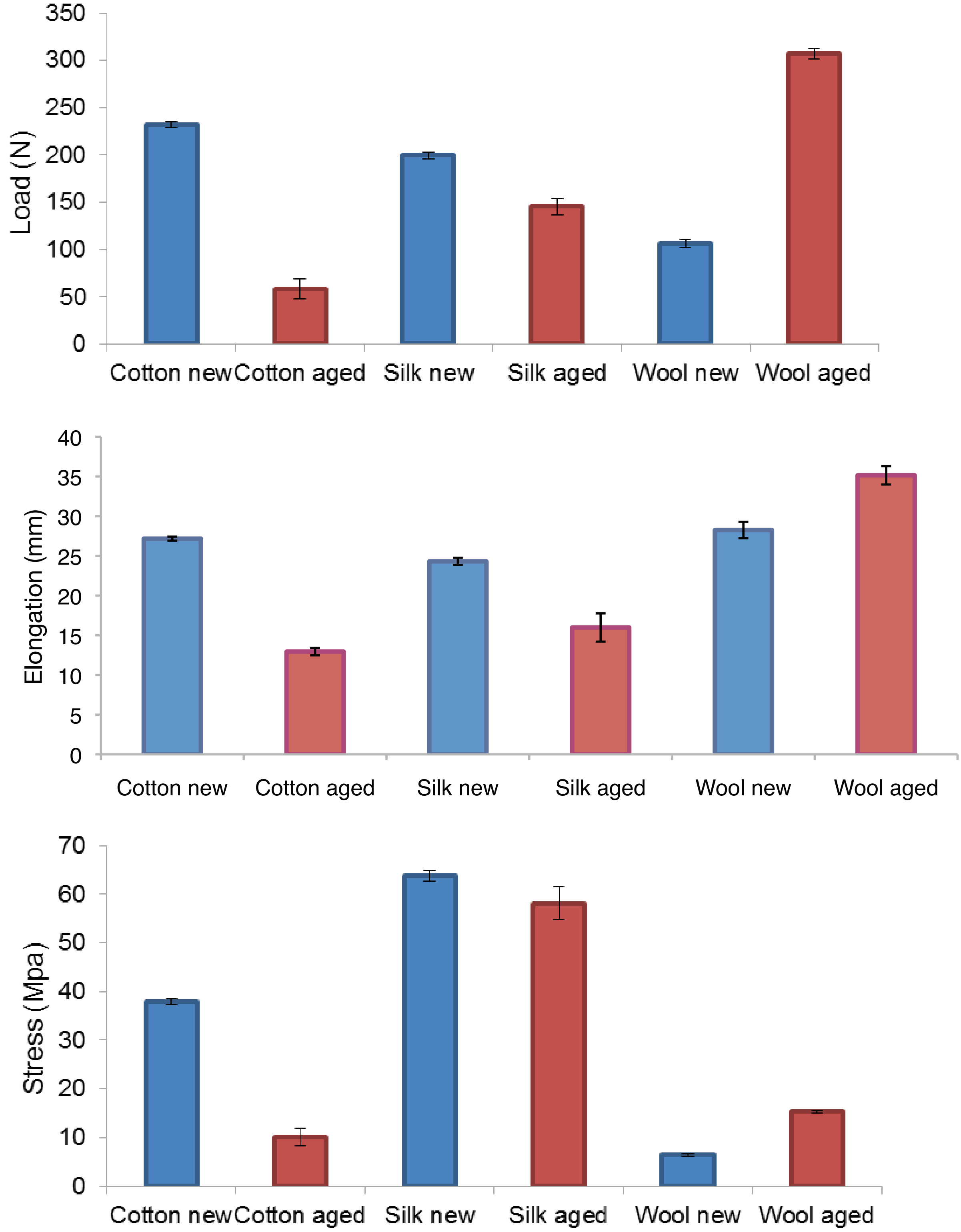

Figure 6.11: New and aged fabrics maximum load, elongation and stress

The new wool was proven by this test to be much weaker than the artefact wool. This was most likely due to the different weave and yarn structures; the weave of the artefact sample was much denser (fig. 6.12).

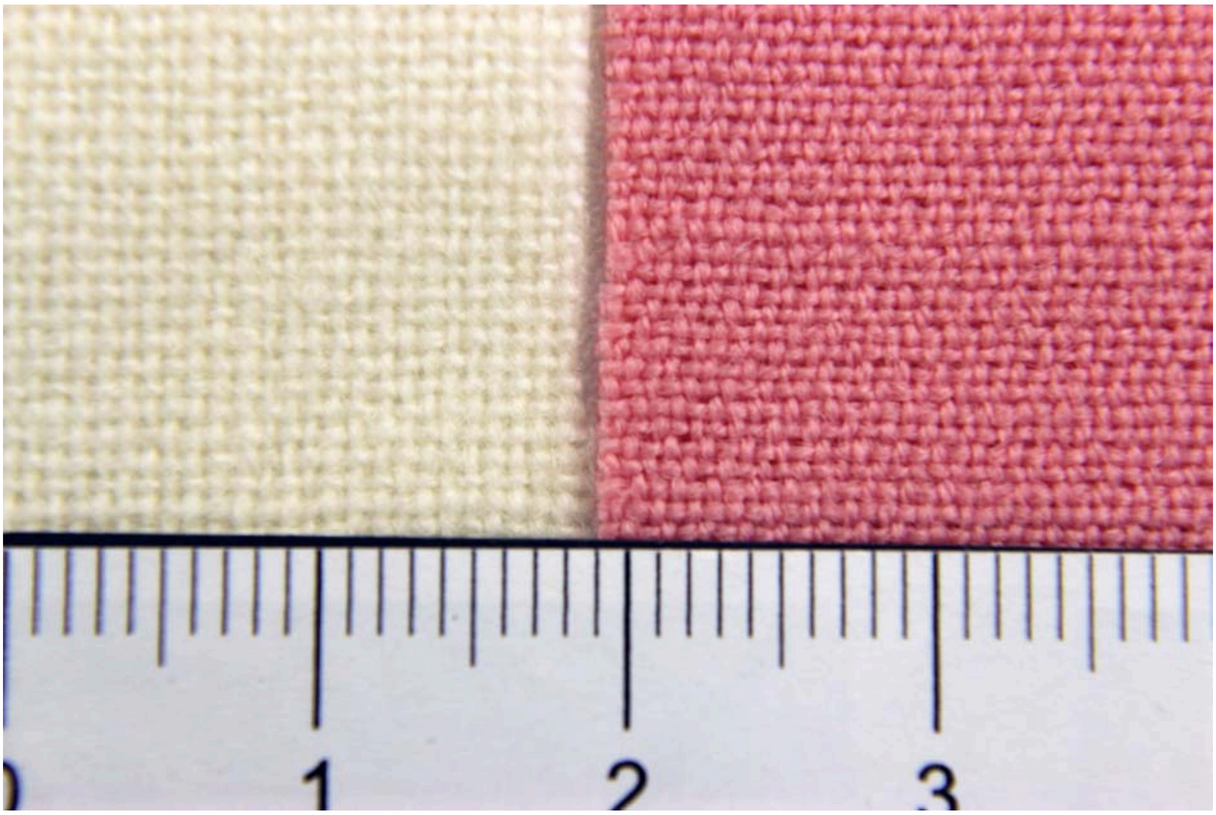

Figure 6.12: Left new wool sample right, artefact wool sample

6.3.2. Conserved new samples (tested to breakpoint)

As only one sample of each was available to test to break, no SD on the histograms could be produced (figs. 6.19-6.21). The goal of this test was to quantify a more appropriate stopping point that would display early signs of damage to the conserved samples and to test whether the threads would break before irreversible damage was done to the fabrics.

Conserved new cotton

Figure 6.13 shows the graphs for new cotton conserved with different threads. The overall curve still appears representative of cotton with no yield point and a fairly straight slope. However, the modulus area is much less steep indicating the conserved sample was less resistant to elongation than the new cotton fabric or thread on its own. As expected with a sample containing a weak area, the maximum load of the samples was much less: the mean maximum load for the new cotton fabric was 214N, and the mean of all the conserved new cotton samples was 39.36N. This was more than a five times decrease in overall strength. However, it should be noted that the cross-sectional areas are slightly different due to the combination of the fabric, support fabric and thread. Conserved new cotton with Skala had a much higher maximum load and elongation than the other samples. When compared to another thread choice, the extent of damage was unmistakable and affected all three components (fabric, support and thread) much more than with Tetex (fig. 6.14).

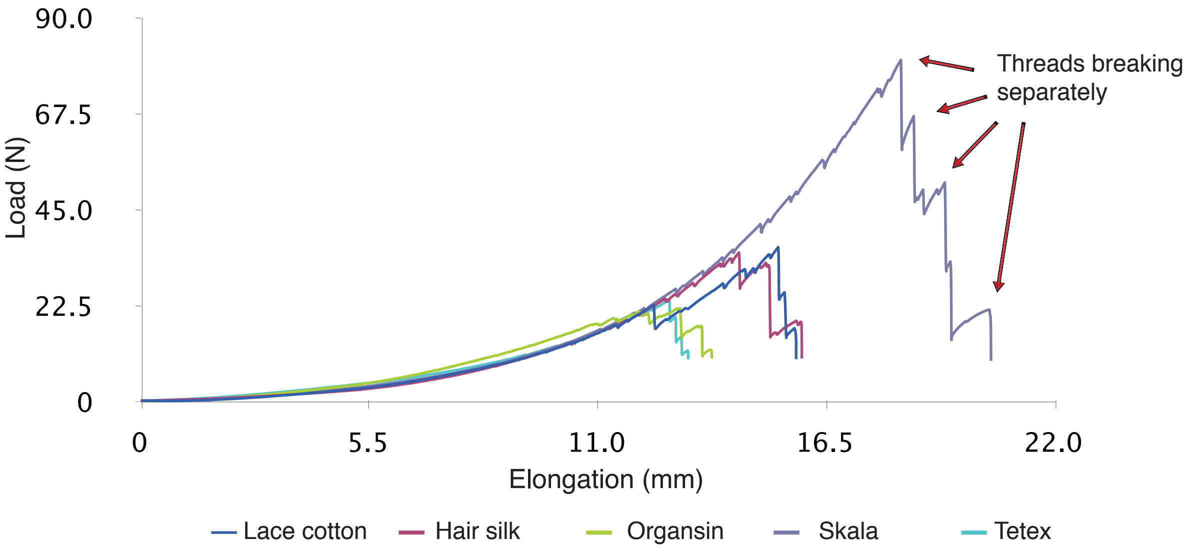

Figure 6.13: Conserved new cotton to break load/elongation curves

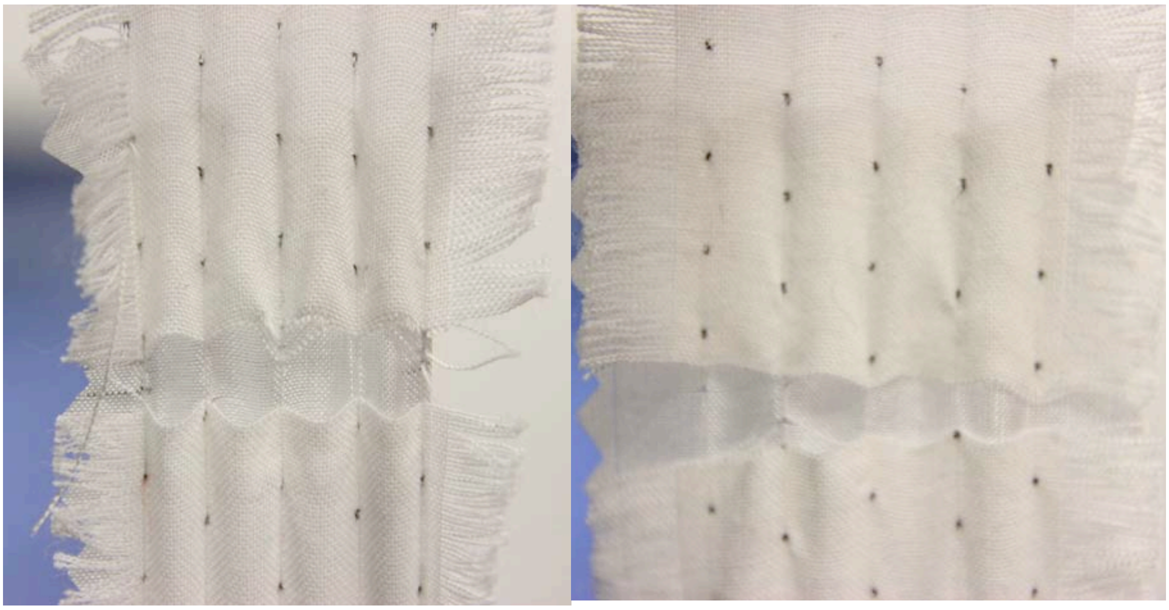

Figure 6.14: Left: cotton with Skala; Right: with Tetex both just before break

Conserved new silk

Figure 6.15 shows that the conservation made the material as a whole different to the silk without conservation and the results were similar to the conserved new cotton group. There was no yield point, and the modulus area was much flatter and straighter than the silk without conservation (fig. 6.10 and 6.15). This could be because the silk fabric had not yet reached its yield point, which occurs at the end of its elastic stretching, by the time the stitching threads broke, indicating that the fabric was still within its elastic state and should still have some recovery. However, damage was done to all three components (new silk, support fabric and threads) and was most severe with Skala and to a lesser degree with hair silk (fig. 6.16).

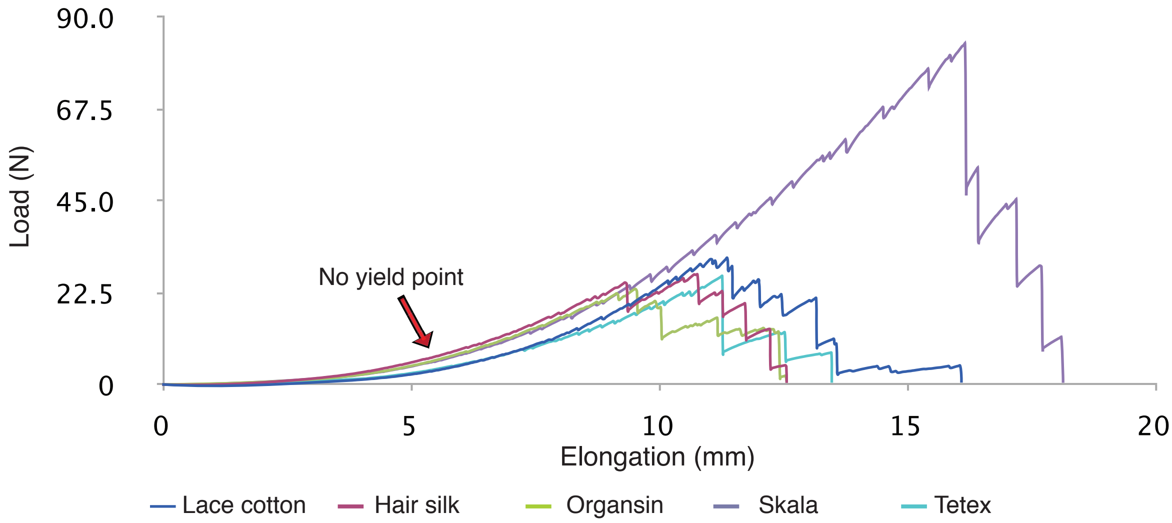

Figure 6.15: Conserved new silk to break load/elongation curves

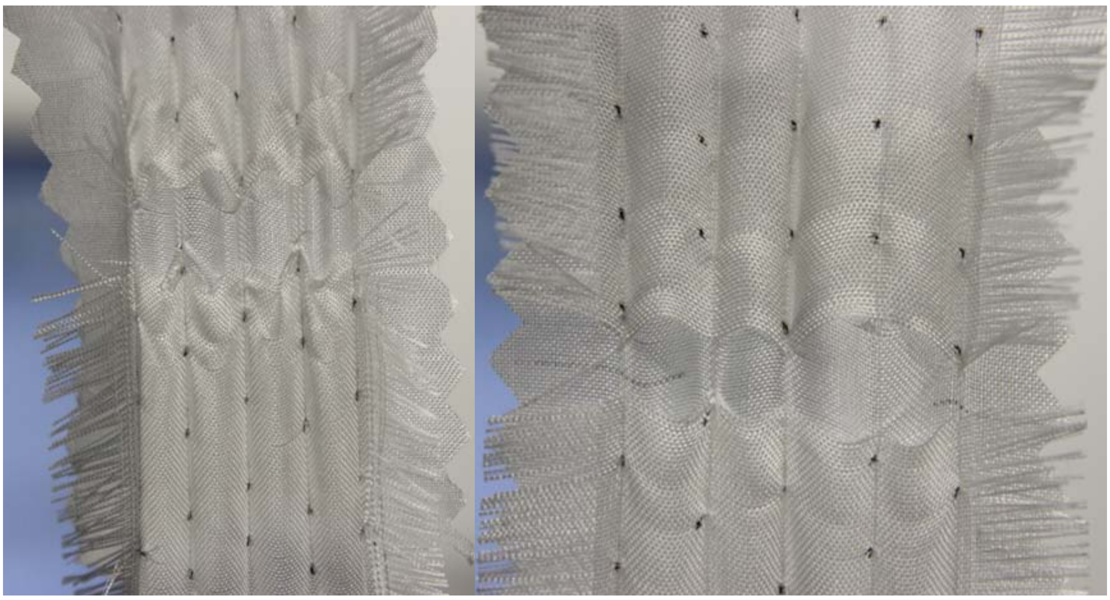

Figure 6.16: Left: silk with Skala (extensive damage all components); Right: silk with hair silk (less damage to all components) both just before break

Conserved new wool

Differences occurred in the wool group compared to the conserved new cotton and silk groups, probably due to the very different structure of this wool (see section 6.3.1). Though the overall graph shape was similar, the different threads did not produce very different results. For example, Skala had very similar results to the rest of the threads, unlike in the conserved new cotton and silk samples. Figure 6.18 shows that although overall load results were much less, extensive damage to all the components still occurred.

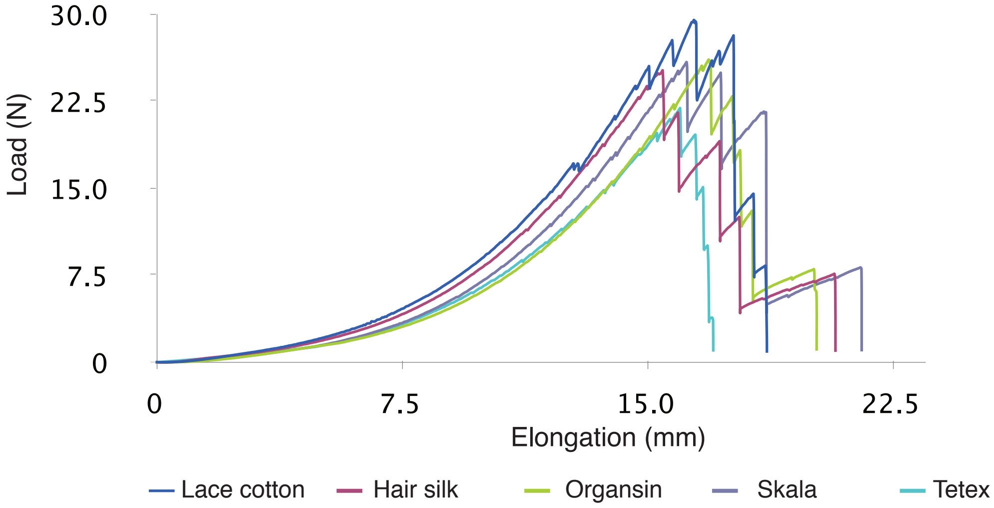

Figure 6.17: Conserved new wool to break load/elongation curves

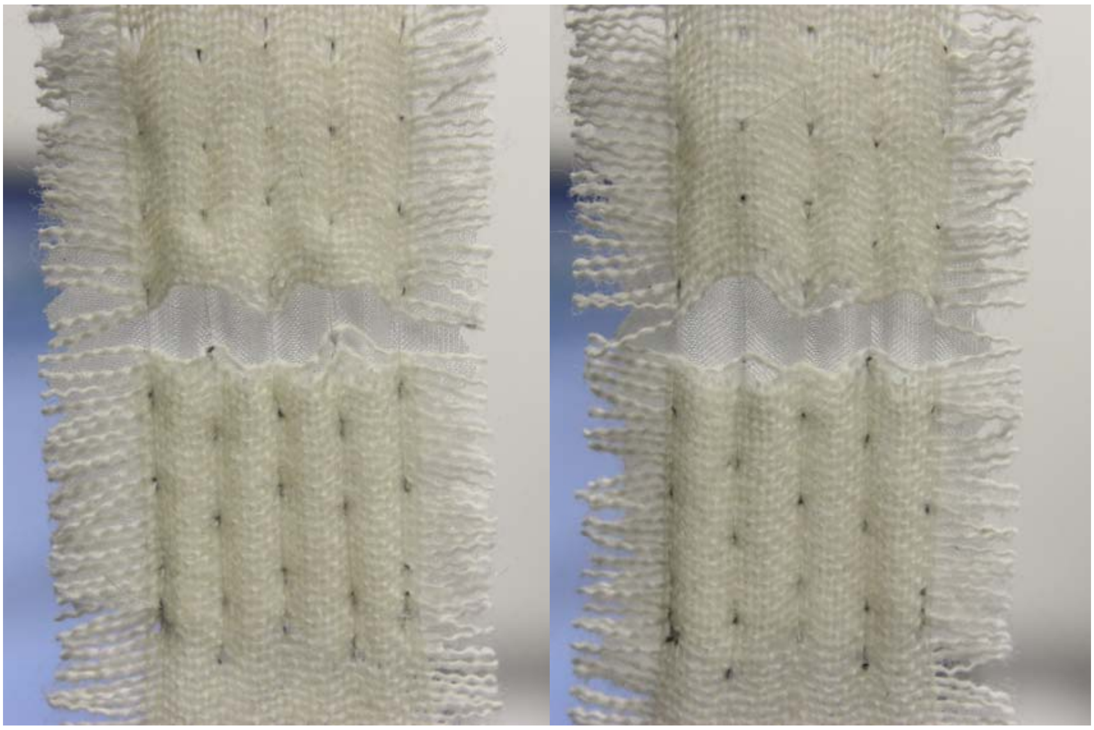

Figure 6.18: Left: wool with lace cotton; Right: with Skala both just before full break

Comparison

Combining each group's properties in the histograms below (figs. 6.19-6.21) highlighted some differences and similarities which may help determine the more appropriate threads for conservation.

- Conserved new silk with Skala had by far the highest overall strength and stress calculation revealing the thread affected the samples' overall properties.
- The silk fabric's weave was able to distort more and allow a continued load and elongation more so than cotton or wool.
- Couching rows on samples placed under stress creates weave distortions between the rows and at the top and bottom of the rows (fig. 6.23).
- Extent of weave distortion depended upon fabric type and overall strength. Cotton fabric exhibited the least amount, while the silk had the highest.
- Stitches placed close to the cut, caused more damage than stitches placed slightly further as they pulled the weave apart when elongated (fig. 6.22).
- The silk patch support exhibited more damage than the fabrics, indicating it acts well as a support preventing some of the damage to the 'artefact'.
- The threads were the weakest point of the conserved samples, however, the theory that threads should break before damage occurs was not supported.
- Conserved new samples with Skala, were generally the strongest with significant amounts of damage. Therefore, it may be determined too strong for many conservation purposes.

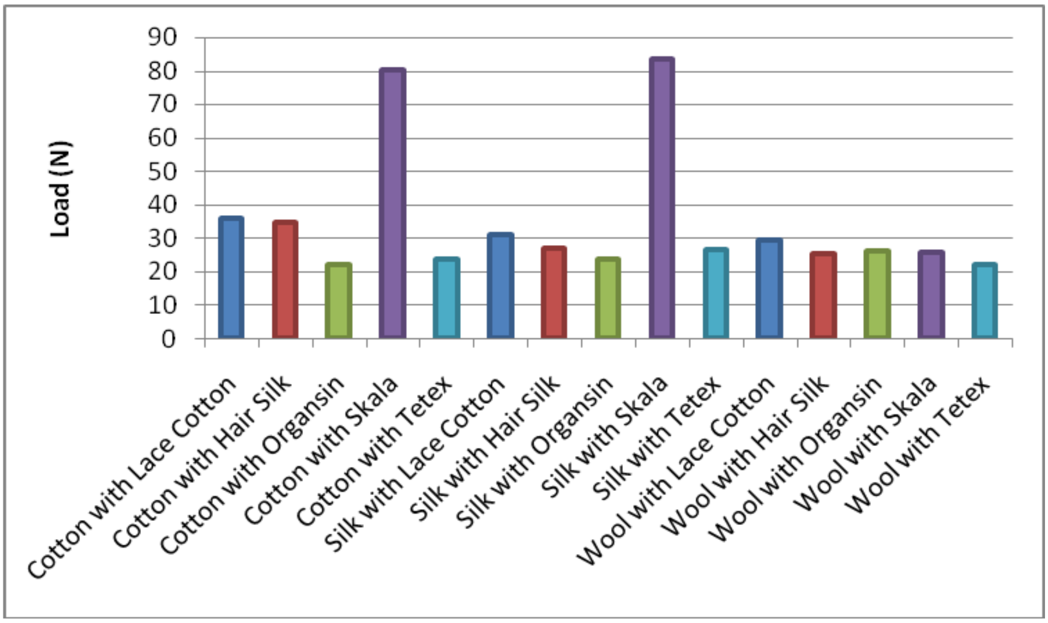

Figure 6.19: All conserved new samples: maximum load

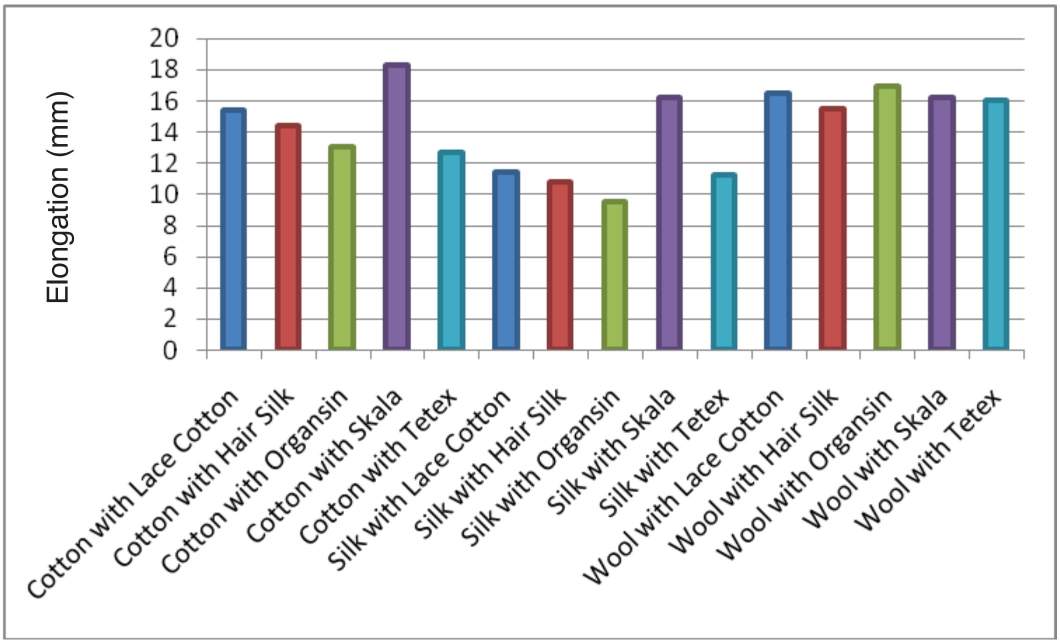

Figure 6.20: All conserved new samples: maximum elongation

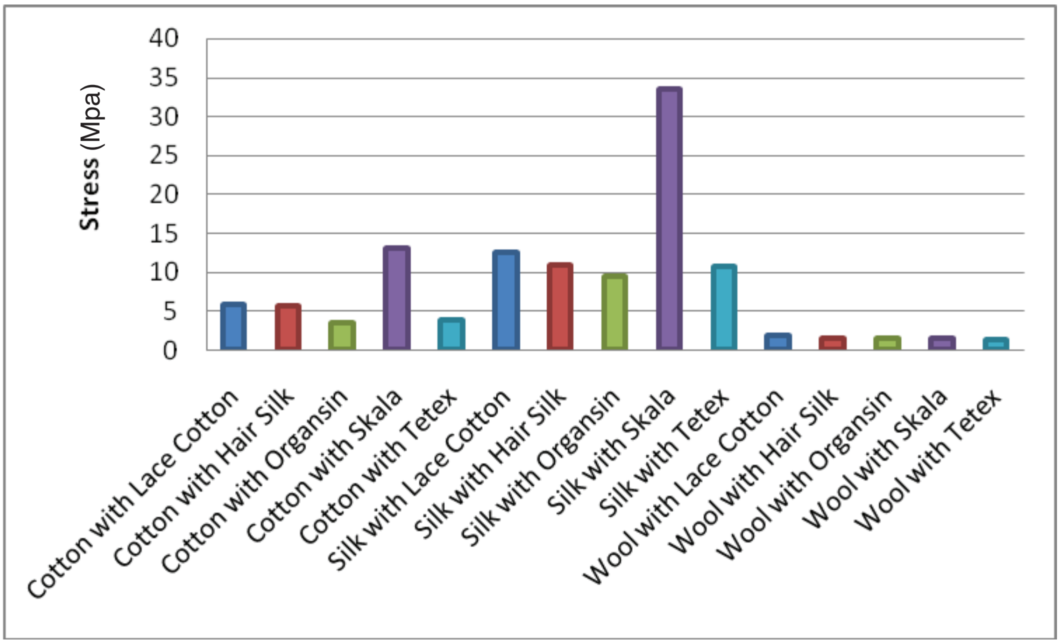

Figure 6.21: All conserved new samples: stress (material strength)

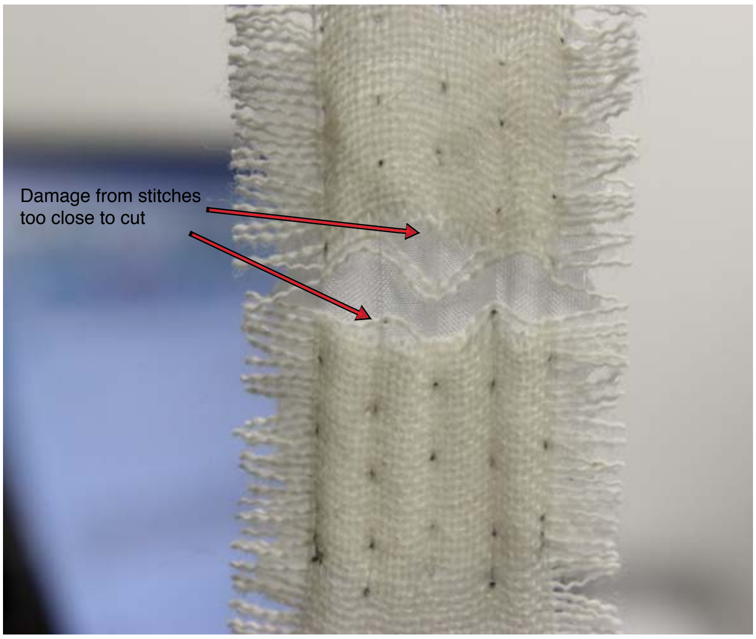

Figure 6.22: Wool with hair silk, weave pulled apart and distortions

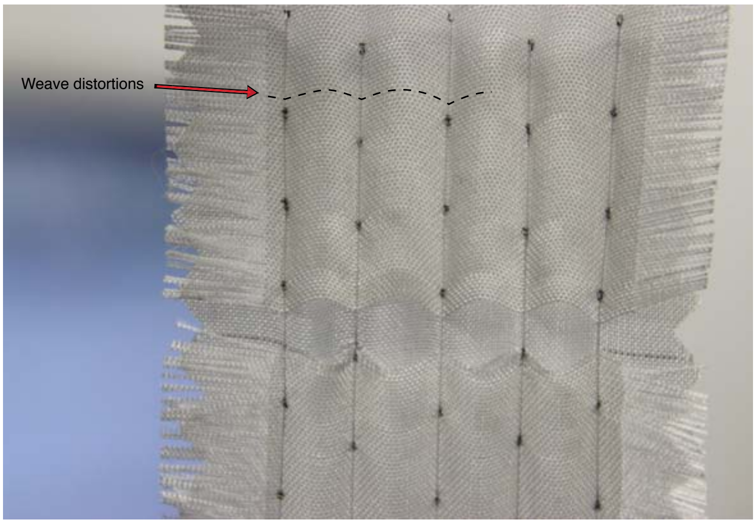

Figure 6.23: Silk with organsin showing weave distortions

6.4. Tensile testing: conserved artefact samples

6.4.1. <u>Data</u>

The goal was to give a comparative set of data showing the effect a couched seam had on the properties related to seam elongation as described in Chapter 5. Below are the graphs (figs. 6.24-6.26) for test groups one through three (cotton, silk and wool). One specimen from each artefact and thread type was chosen to be representative of the four replicates of each variation and was used to compare between test group sets.

Seen in section 6.4.2, the SD for the five different threads used to conserve each test group set were not significantly different from each other. Therefore a specimen representative of the group was chosen to make the seam elongation graphs (fig. 6.27, 6.28 and 6.29).

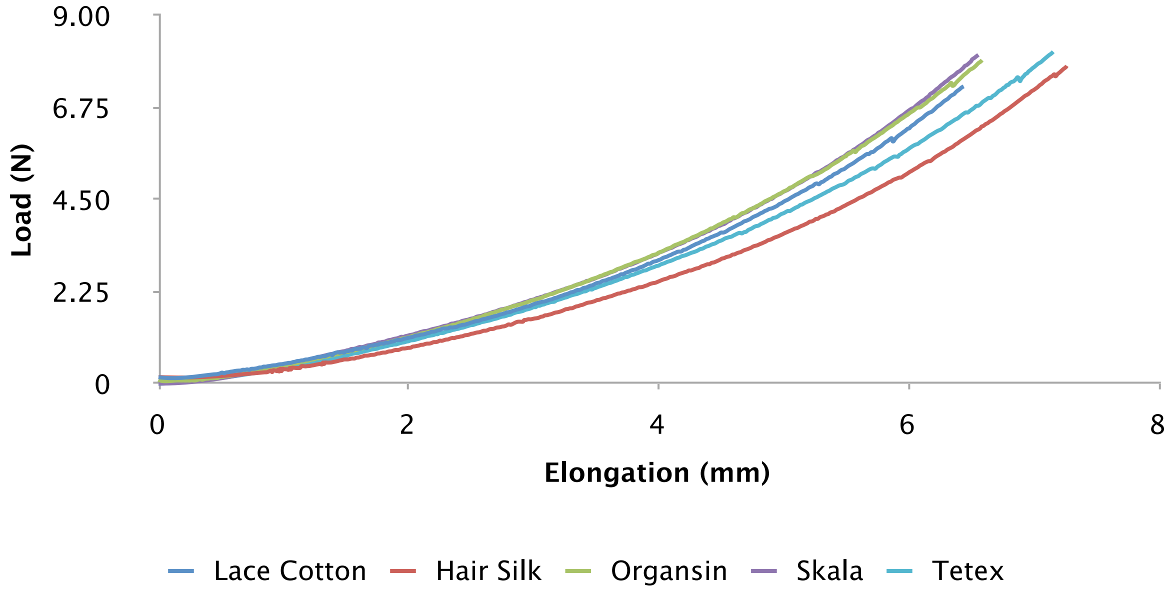

Figure 6.24: Test group 1; cotton load/elongation curves to 8N

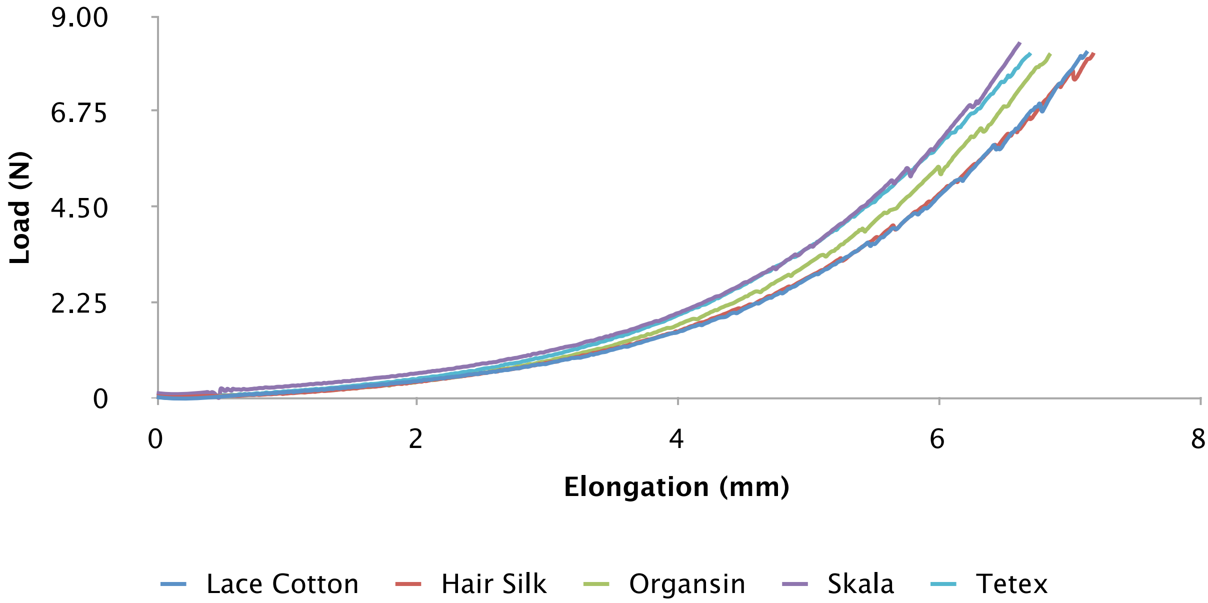

Figure 6.25: Test group 2; silk load/elongation curves to 8N

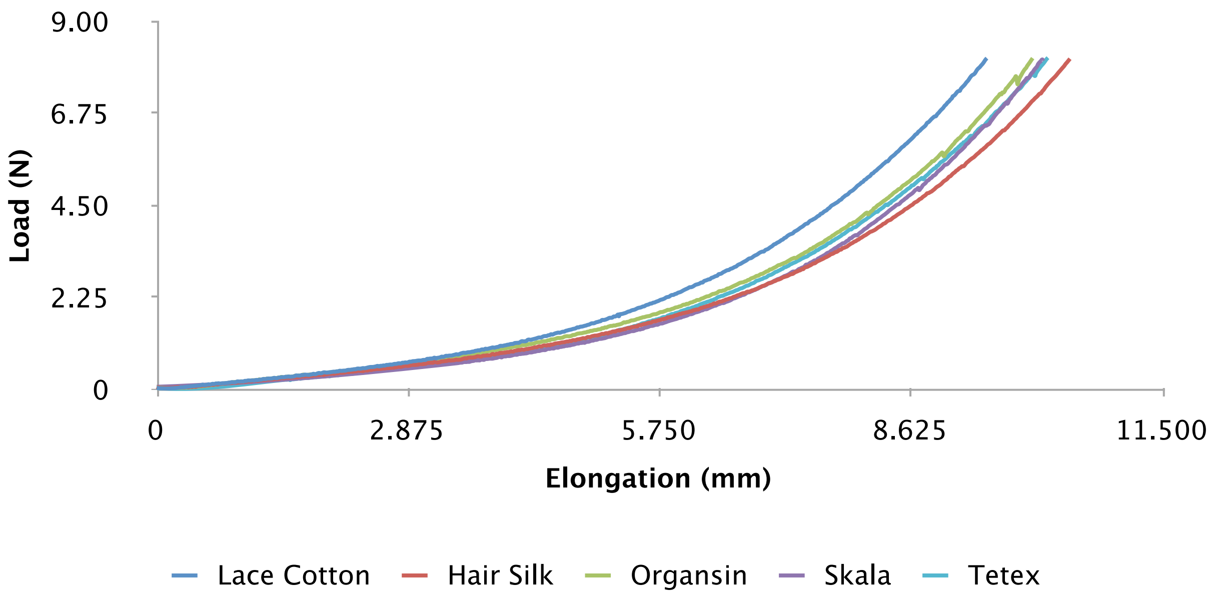

Figure 6.26: Test group 3; wool load/elongation curves to 8N

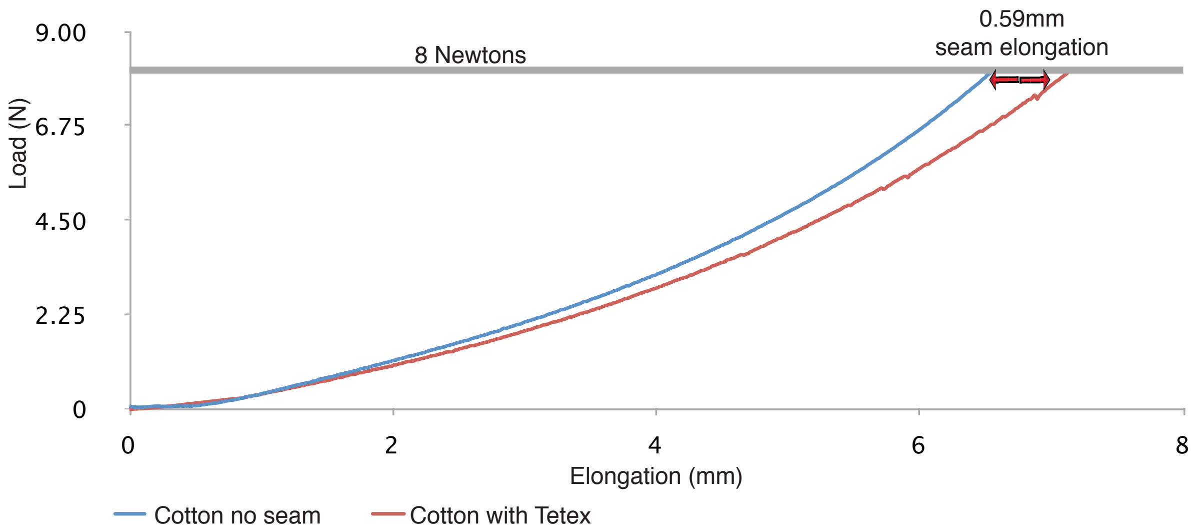

Figure 6.27: Seam elongation method adaptation, test group 1; cotton

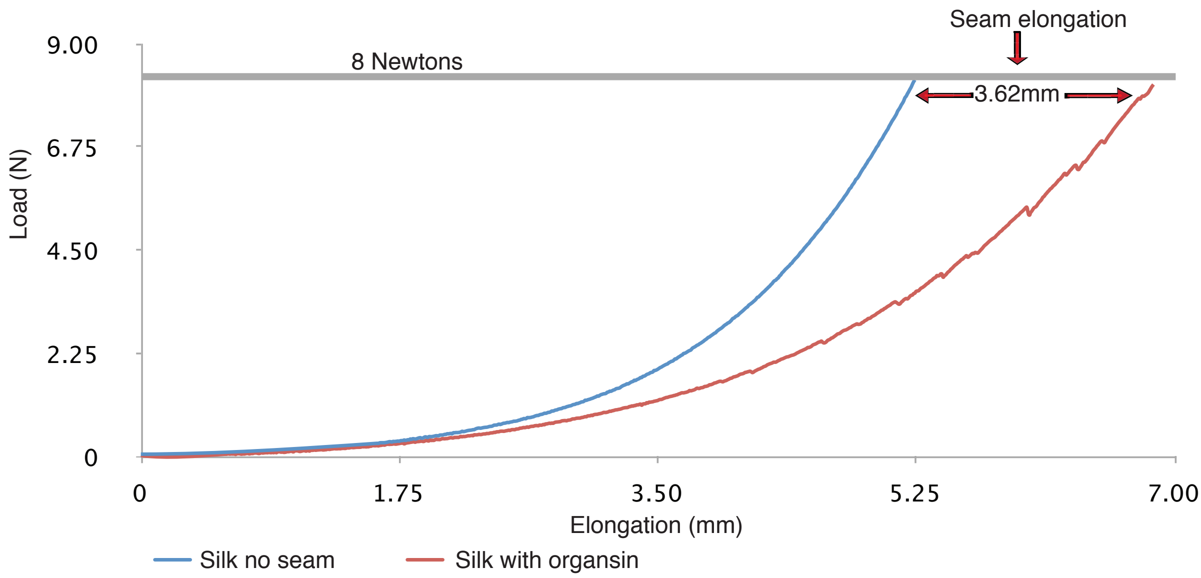

Figure 6.28: Seam elongation method adaptation, test group 2; silk

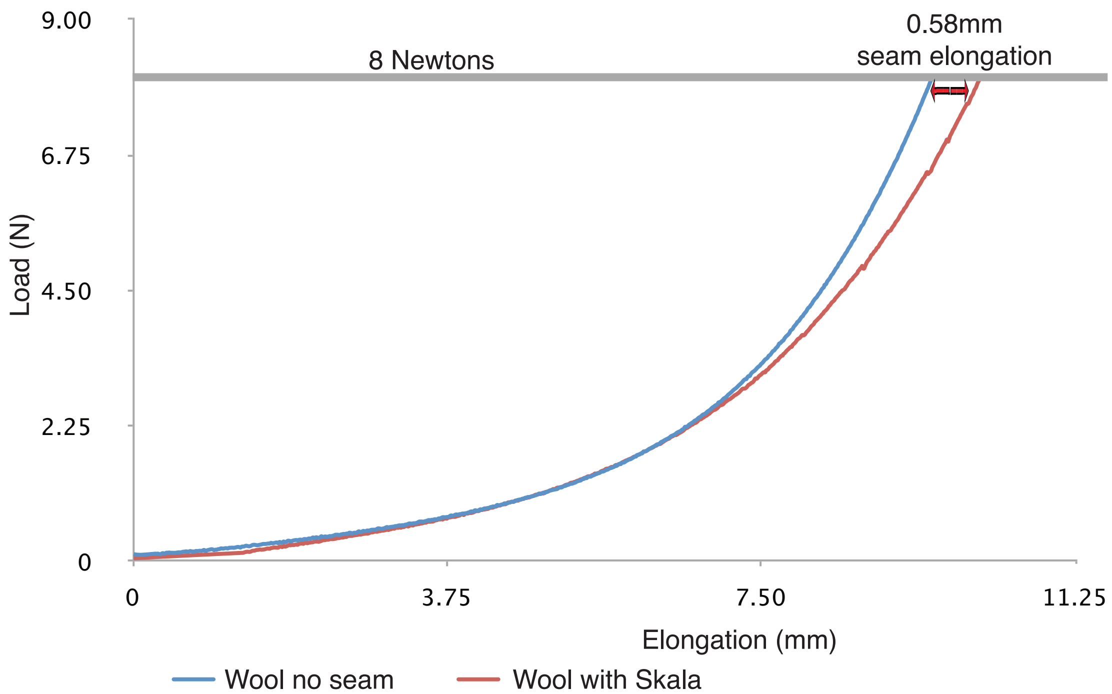

Figure 6.29: Seam elongation method adaptation, test group 3; wool

6.4.2. Statistical analysis

The SD histogram (fig. 6.30) shows the elongation of all the test groups (cotton, silk and wool sets) were compared to each other and to the un-conserved artefact samples. Load had no SD as it was stopped at 8N. The SD error bars for elongation determined that within each set there was no significant difference between thread types. For example, cotton conserved with lace cotton was not significantly different from cotton conserved with Skala. There was also no significant difference between the cotton and silk test groups, with the exception of cotton with Tetex which had a slightly greater elongation. These sets were also significantly the same to cotton with no conservation. This was unexpected as a weak area should increase elongation possibilities. In general, SD bars were fairly long, indicating that the materials and samples are heterogenous (see section 5.10.3 Statistical analysis). In addition, as only four samples of each variation were tested, a greater SD was able to occur. If more samples were tested, the SD could have been less giving higher accuracy and reproducibility.

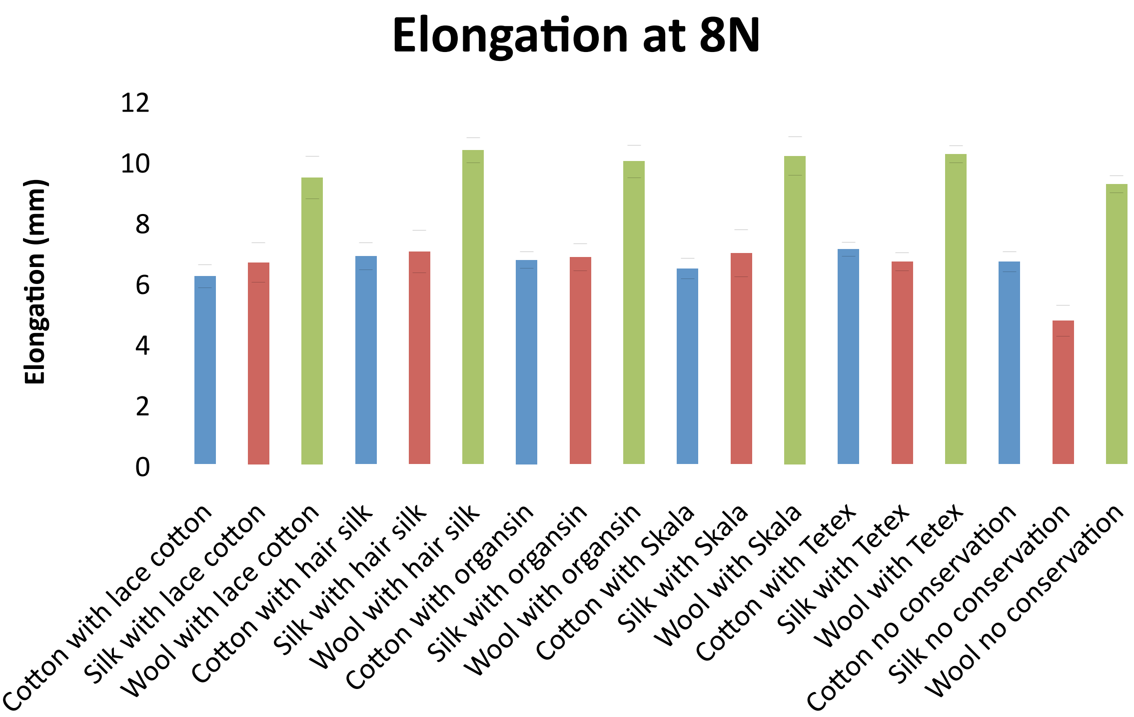

Figure 6.30: Standard deviation for conserved artefact samples and artefact fabrics

6.4.3. Results and discussion

When comparing graphs from figures 6.24-6.26, it was noted in test group 1 cotton, the graphs had the typically straighter curve showing the material was more resistant to elongation. In contrast, graphs from test group 2 silk and 3 wool had a more concave curve indicating the materials were less resistant to the load at the beginning and increased in resistance as the elongation continued. The thread material did not appear to affect the overall graph slopes and shapes. For example, the lace cotton thread did not give the silk and wool test groups a straighter slope. The seam elongation graphs (figs. 6.27-6.29) revealed that the conserved artefact samples had some property changes in the overall material and this was significantly different between the test groups as seen through SD. Test group two's silk sample had a much higher seam elongation of 3.62mm compared to 0.59 and 0.58mm for test group one cotton and three wool respectively. This showed that the silk group as a whole had more overall elongation in comparison to the silk fabric with no conservation. The difficulty of maintaining even tension when stitching the fine fabric, and/or the material's properties as a whole could be explanations (see section 6.6 for stitching observations).

Test group one cottons' elongation results were not significantly different from each other or from the cotton fabric with no conservation. This materials' heterogenous nature may explain the slightly higher SDs. Compared to test group two silk, which also exhibited fairly high SDs, the silk with no conservation was significantly different from the conserved artefact samples. This was expected due to the nature of adding stitching, but the greater difference in silk compared to cotton and wool groups could be due to silk's hard filament structure. Similarly to the cotton group, the wool group was not significantly different from wool with no conservation. However, it was significantly different when stitched with Tetex and hair silk, but only by a small amount. These results may be for the same reasons as with the cotton sets. In addition, cotton and wool have a softer staple structure that is more compressible, which is a reason why the addition of a seam did not make a significant effect on the overall elongations.

Damage to any one of the components (artefact fabric, patch support or thread) appeared to occur before a load of 8N. The silk group appeared to exhibit damage by 5N but was continued to 8N to maintain comparability. Most of the conserved artefact samples appeared to recover to almost their original positions, however, the threads did not and remained loose upon the textile. All samples stitched with hair silk initially appeared during testing to have the greatest elongation, which was confirmed by the results. This could be due to the difficulty of maintaining good tension while stitching with this particular thread (see section 6.6.1).

6.4.4. Microscopic evaluation

High-magnification images provided details of the comparisons between the different thread and fabric sets. First, stereomicroscope photography was used to analyse all the samples (figs. 6.31-6.34). Second, the before and after tensile testing of select samples using SEM is evaluated (figs. 6.36 and 6.37).

Stereomicroscope evaluation

Photographs using the stereomicroscope gave information about each set of samples, and allowed them to be compared to the results from the fixed-load experiment (section 6.5 and Appendix 9.7). It should be noted that only one sample of each was evaluated and the degree of damage was by visual analysis and was therefore subjective. Damage may include weave distortions and compression, size of stitch holes and permanent damage to the threads.

The conserved cotton artefact with Tetex displayed the highest degrees of damage. There was a much larger hole created by the stitch and a fair amount of weave compression at the backstitches (fig. 6.31). The conserved wool artefact group exhibited very low degrees of damage as well as the conserved artefact silk with lace cotton and hair silk (fig. 6.32). The wool fabric was not very degraded and the structure of the weave and fabric yarns were able to absorb the load and recover afterward. However, the threads were not able to recover fully seen by the testing photos (figs. 6.33 and 6.34). The conserved artefact cotton group exhibited the highest levels of damage overall, indicating that the fabric was more degraded and susceptible to damage than the other two artefact samples. The conserved artefact silk group displayed some damage throughout with more weave distortions similar to that in the fixed-load experiments (section 6.5). The thread that exhibited the highest levels of damage to the artefact fabric throughout the groups was Tetex, while the other threads varied more. Conserved artefact cotton with hair silk and conserved artefact silk with organsin also showed higher damage (see Appendix 9.7 for full evaluation).

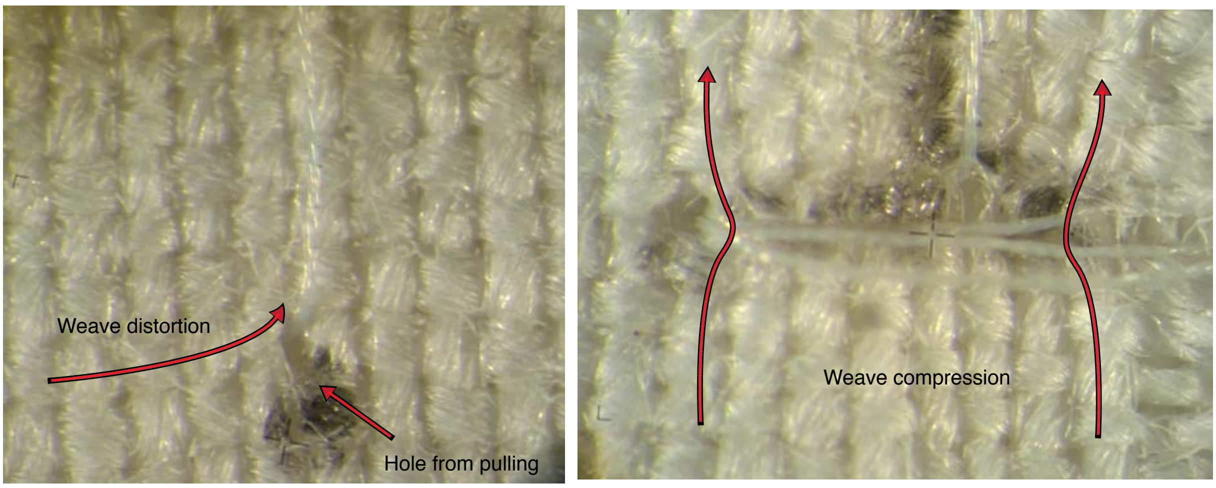

Figure 6.31: Cotton with Tetex stitch hole and weave compression, most damage

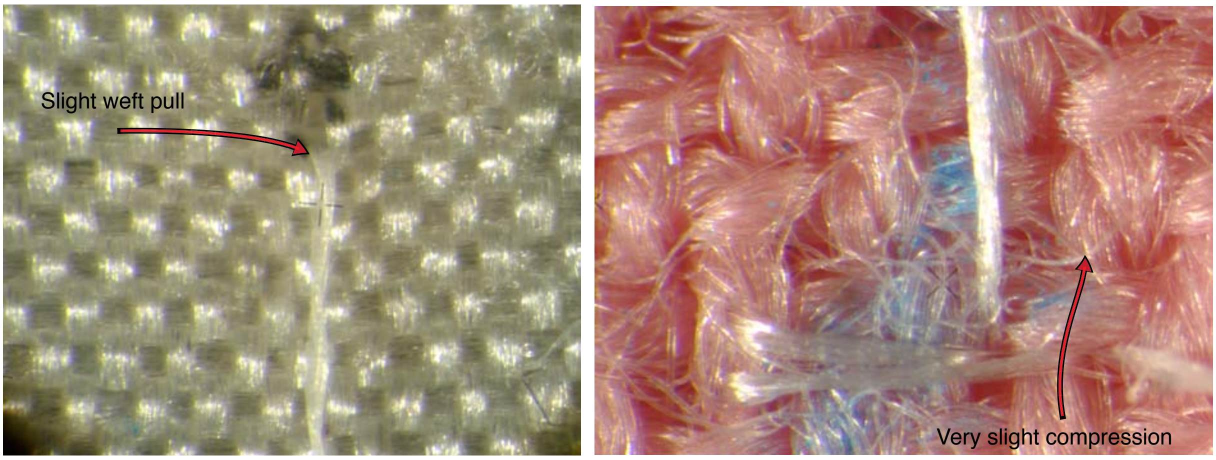

Figure 6.32: Left: conserved silk with hair silk; Right: wool with organsin, least damage

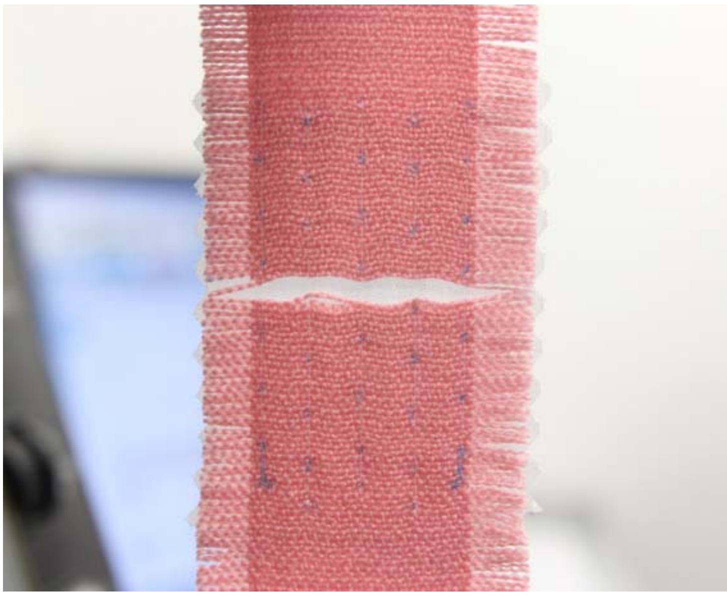

Figure 6.33: Wool with Tetex at 8N, weave stress and stitch point holes observed

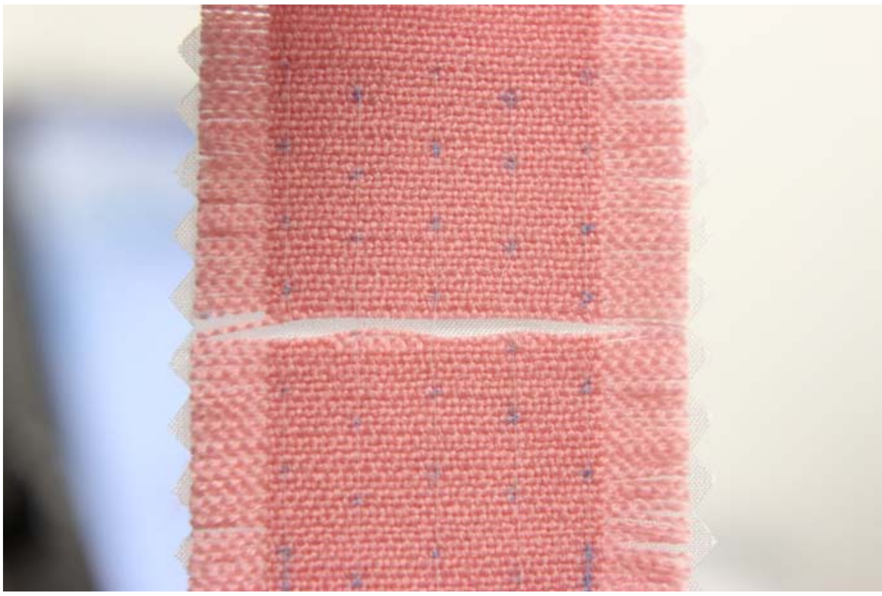

Figure 6.34: Wool with Tetex after load removed; wool recovered, threads do not

SEM evaluation

Although the SEM samples only showed a small selection, it did allow a comparison between a few threads as well as the fabrics. Conserved artefact cotton with lace cotton (fig. 6.35), although tested at a lower load (refer to 5.7.3), still had an increase in the hole length caused by the stitch as well as a slight increase in the weft weave distortion. Conserved artefact cotton with Tetex was chosen for after SEM as it was originally thought the thread had cut through the yarns, however, as seen by SEM (fig. 6.36), the weft yarn is still connected but has been pulled down. There were a few fibres that appeared to have been fractured (or cut) by the thread, and it is possible that more damage of this kind could occur if the load was applied for a longer time period. Conserved artefact silk with Skala showed definite weave distortions and damage at the stitch point hole (fig. 6.37). However, the overall damage was minimal considering the amount of force it was placed under (fig. 6.38). Conserved wool artefact with Skala did not visually appear to have much damage to the wool. However, measuring the stitching hole revealed that it increased by more than two-thirds, indicating the yarn and weave structure could absorb the load without greatly affecting the weave (fig. 6.39).

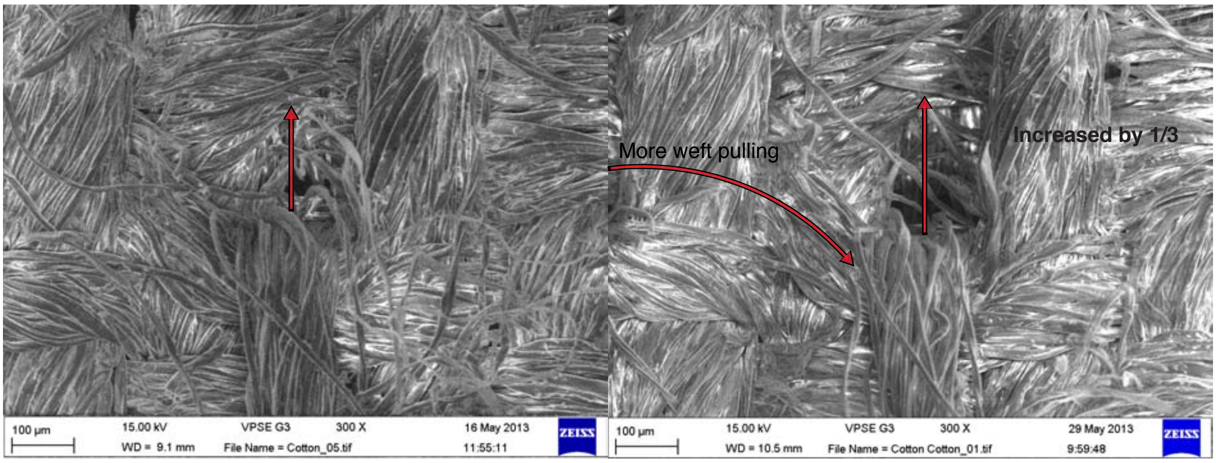

Figure 6.35: Cotton with lace cotton, Right: before, Left: after tensile testing at 6N[95]

[95] Note: see section 5.7.3 explaining different load amount.

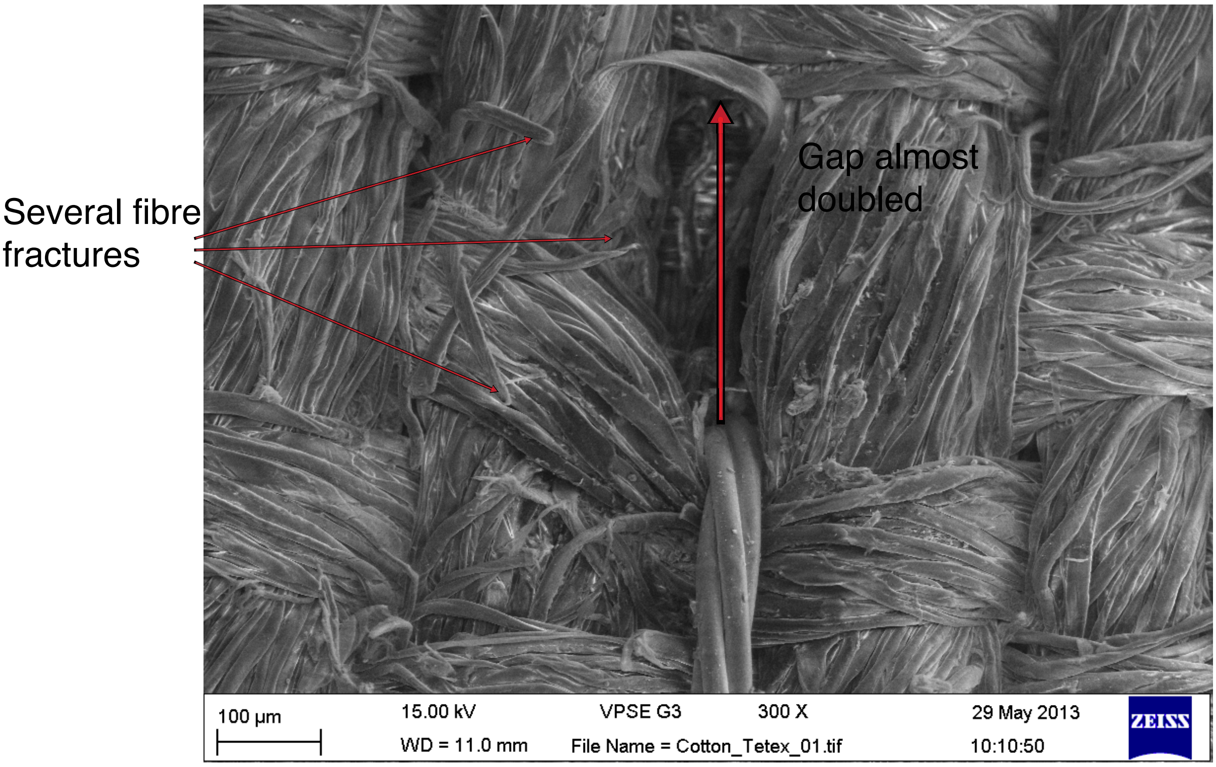

Figure 6.36: Cotton with Tetex after tensile testing at 8N

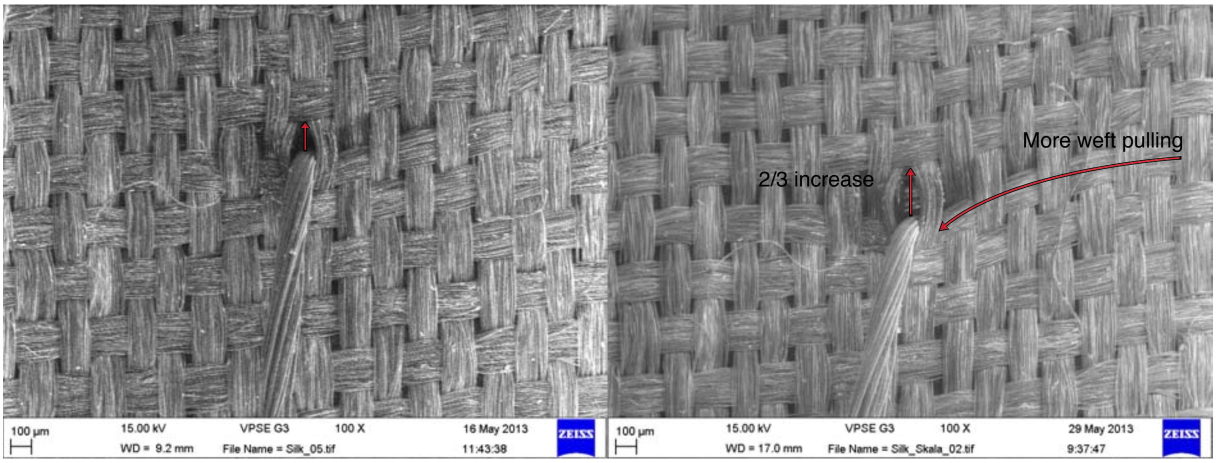

Figure 6.37: Silk with Skala, Left: before; Right: after tensile testing to 8N

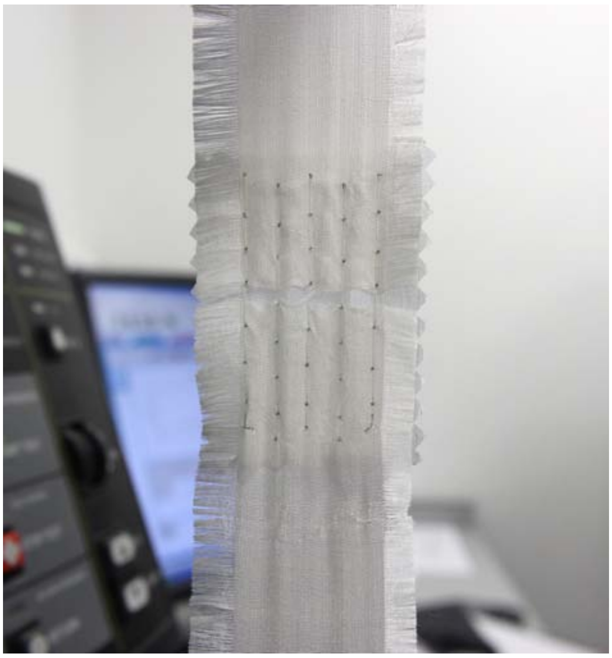

Figure 6.38: Silk with Skala visual at 8N

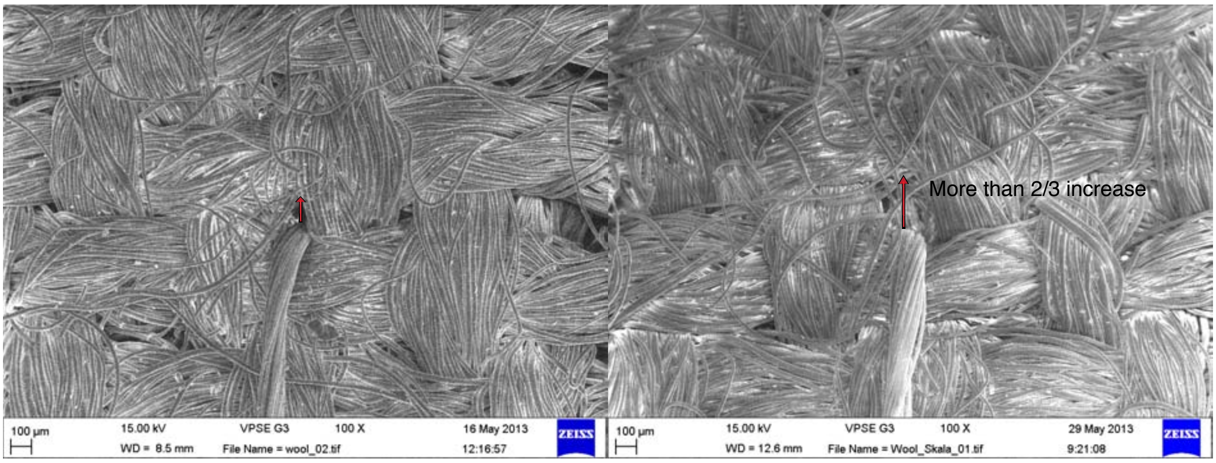

Figure 6.39: Wool with Skala, Left: before; Right: after tensile testing at 8N

6.5. Fixed-load test: conserved artefact samples

6.5.1. Data

Information is presented in two different ways. The first three pairs of photos (figs. 6.40-6.42) demonstrate how the three different fabrics: cotton, silk and wool, responded directly after the weights had been applied. The second set (fig. 6.43) is an example of the photos taken throughout the experiment approximately every three days and directly after the weights were removed, see Appendix 9.6 for complete measurement data. Conserved silk artefact with lace cotton was chosen to demonstrate each stage of the experiment as it had a measurement change at each interval (fig. 6.43). The measurement of the elongation was taken at the point of maximum distortion, where a couching line crossed the cut in the fabric (fig. 6.40, at 0.57mm gap).

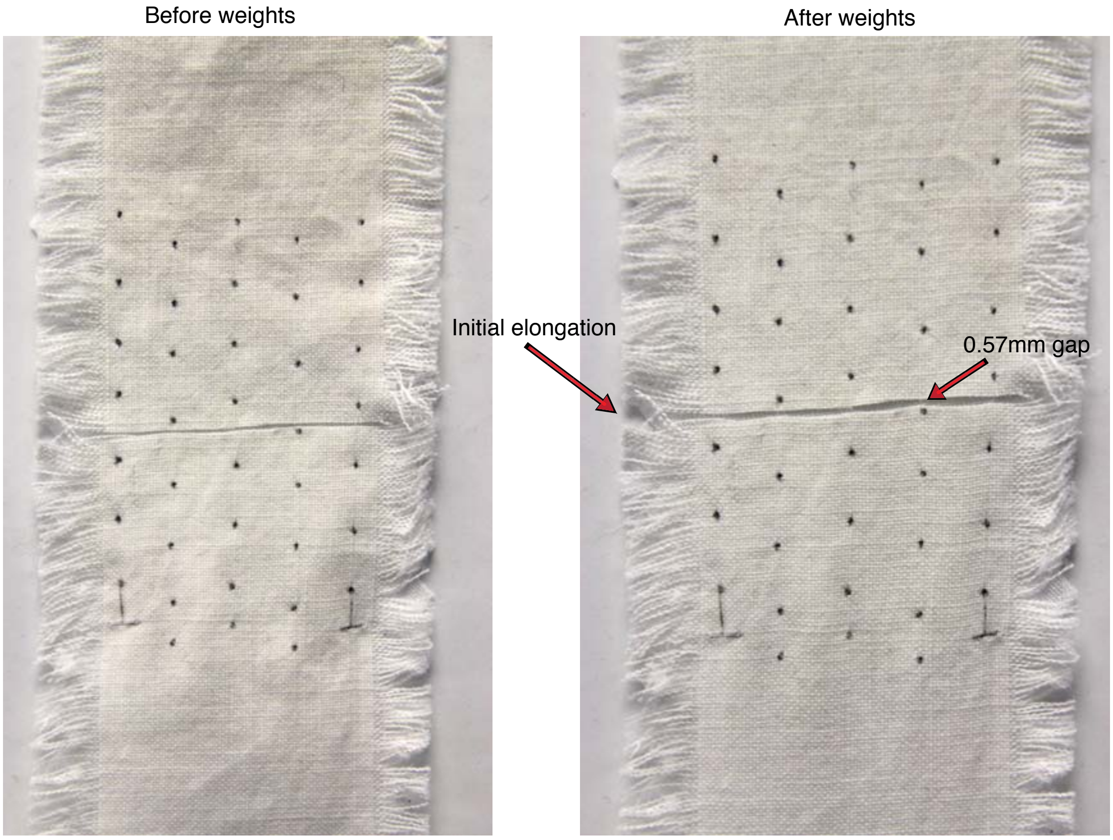

Figure 6.40: Cotton with Tetex before and after initial loading with weights; sample showed the least elongation

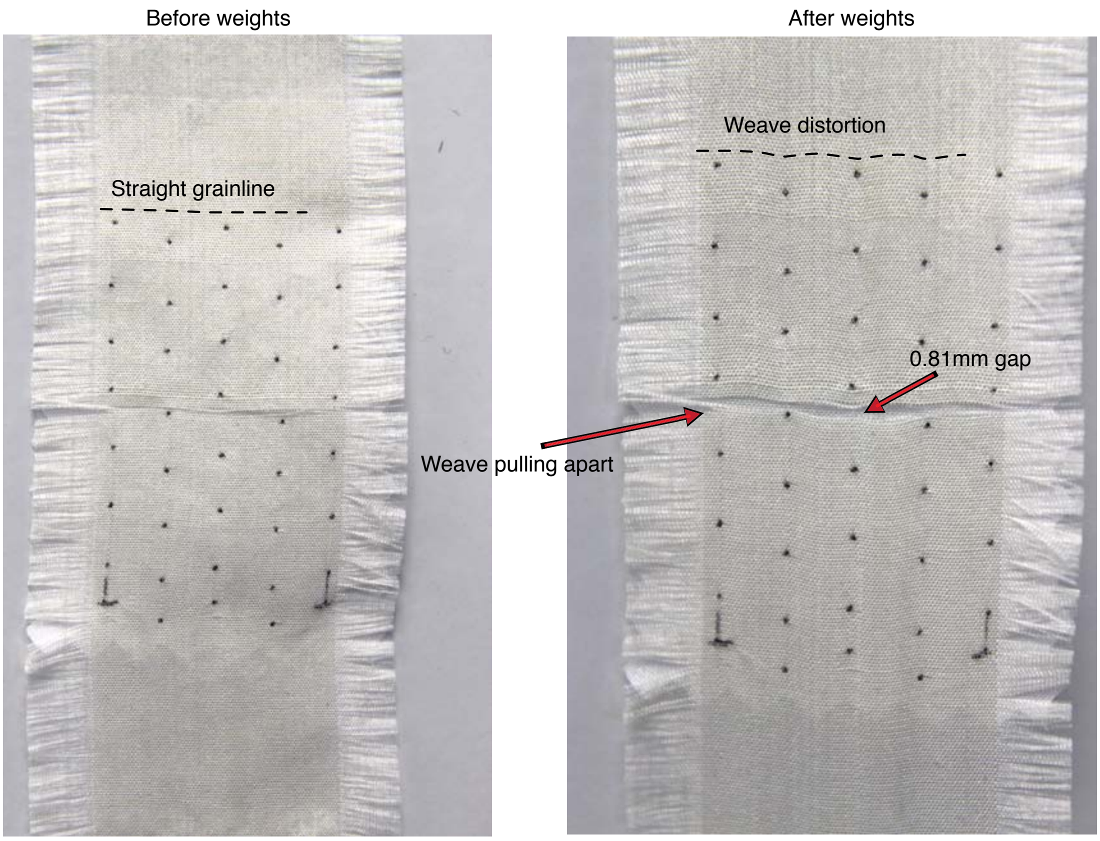

Figure 6.41: Silk with Tetex before and after initial loading with weights; sample showed the most elongation

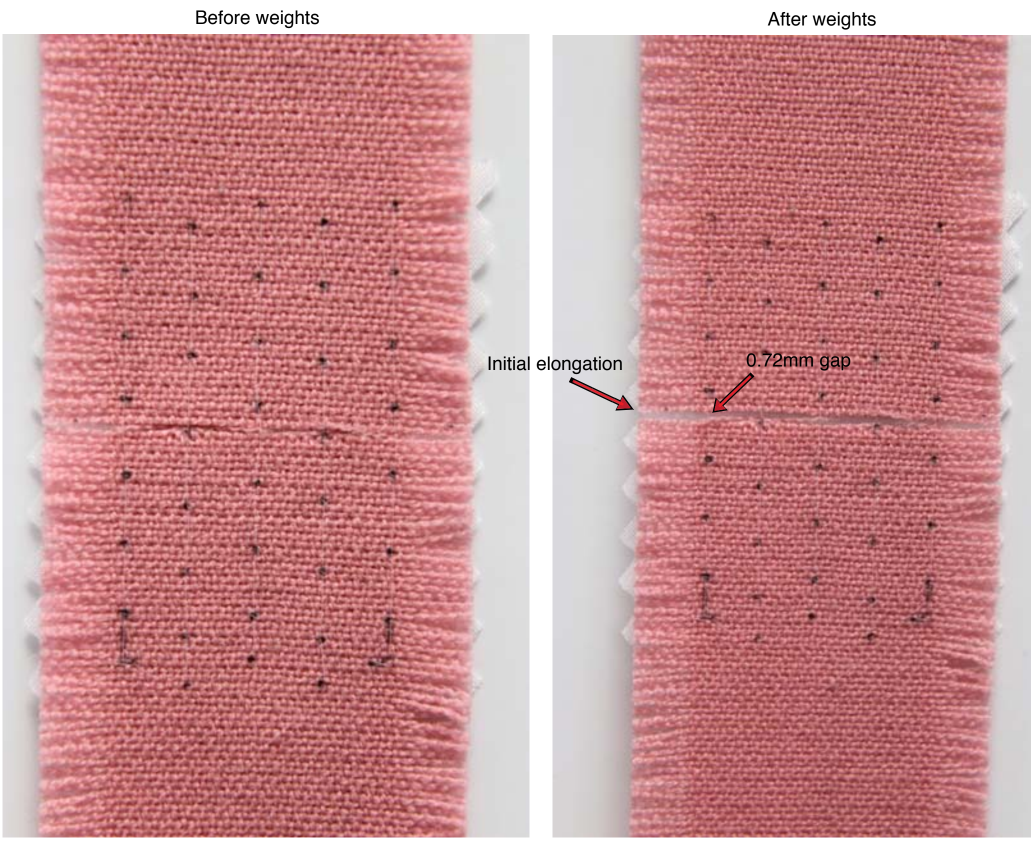

Figure 6.42: Wool with Tetex, before and after loading with initial weights

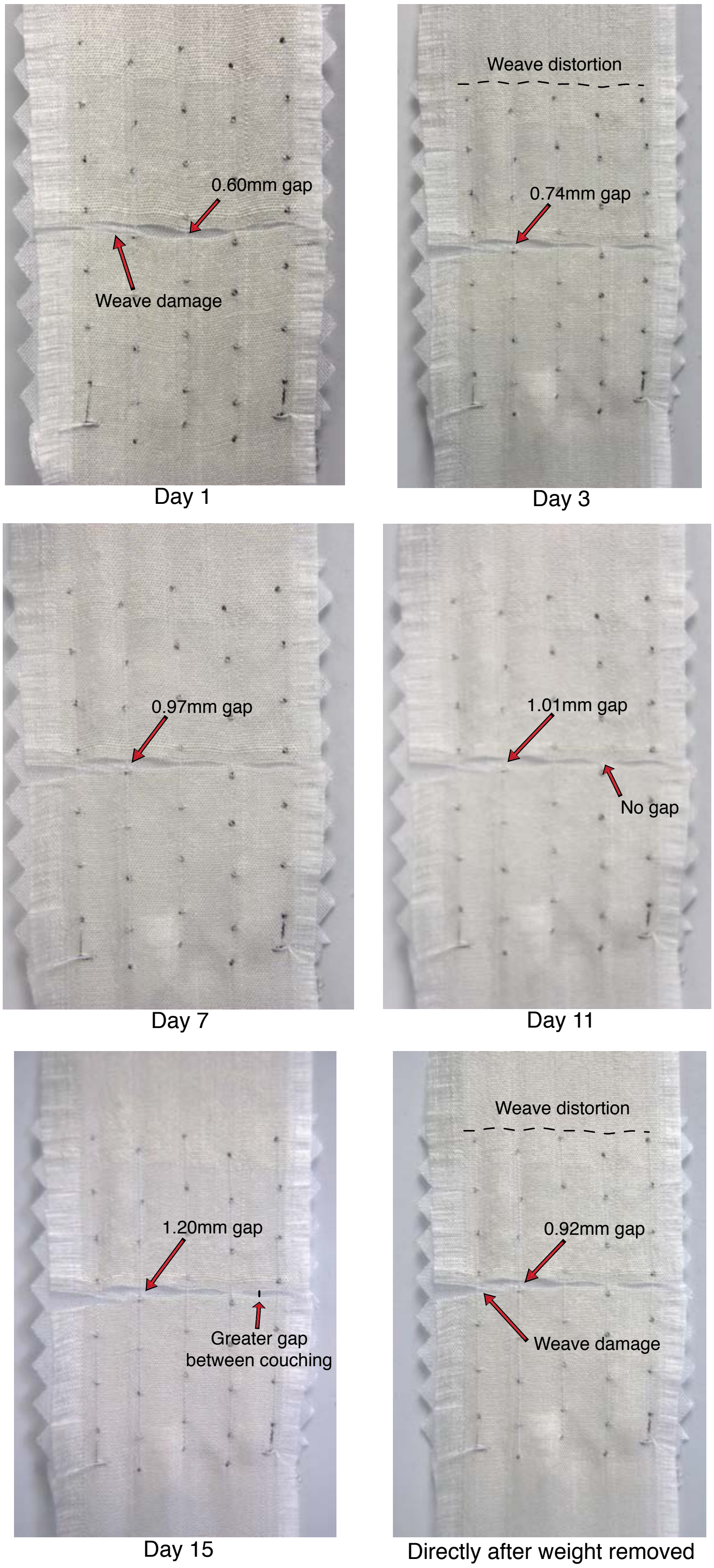

Figure 6.43: Silk with lace cotton loaded over 15 days

6.5.2. Statistical analysis

As only one of each sample was available to use for this study no SD could be computed.

6.5.3. Results and discussion

A few interesting examples will be discussed in this section, see Appendix 9.6 for measurement results. The elongations of the samples were too small to depict graphically, so the focus is on visible damage as described in 6.4.4. It was noticed that some threads stretched a significant amount creating a gap between the two cut points of the specimen.

Cotton artefact group

Within the cotton artefact group, the sample with organsin displayed the greatest maximum elongation with 1mm and the least amount of initial recovery after the weights were removed: only 0.09mm. Tetex had the least amount of elongation of all the cotton samples with a maximum of 0.67mm and medium recovery of 0.14mm. The lace cotton sample exhibited the greatest recovery with 0.27mm. This was not expected as cotton as a material has poor recovery. On visual analysis alone, the cotton samples appeared fairly resilient to weave distortions and pulling apart of the weave, possibly due to the close weave count and the fibres' staple structure allowed more even weight distribution. However, some weave distortions were seen by day three on some samples and all samples exhibited some weave distortions by the final day. There was better recovery of the distortions than with the silk artefact group (see below). The most extreme examples of damages observed were cotton with Tetex and hair silk (fig. 6.44). These results do not necessarily correspond with the thread tests as hair silk was expected to have better recovery and Tetex a greater elongation. Not all couching rows elongated the same amount and some areas extended more than others over different periods of time (fig. 6.43). These results determine that perfectly even tension while hand stitching is not possible and that samples comprised of more than one material becomes heterogenous as a whole.

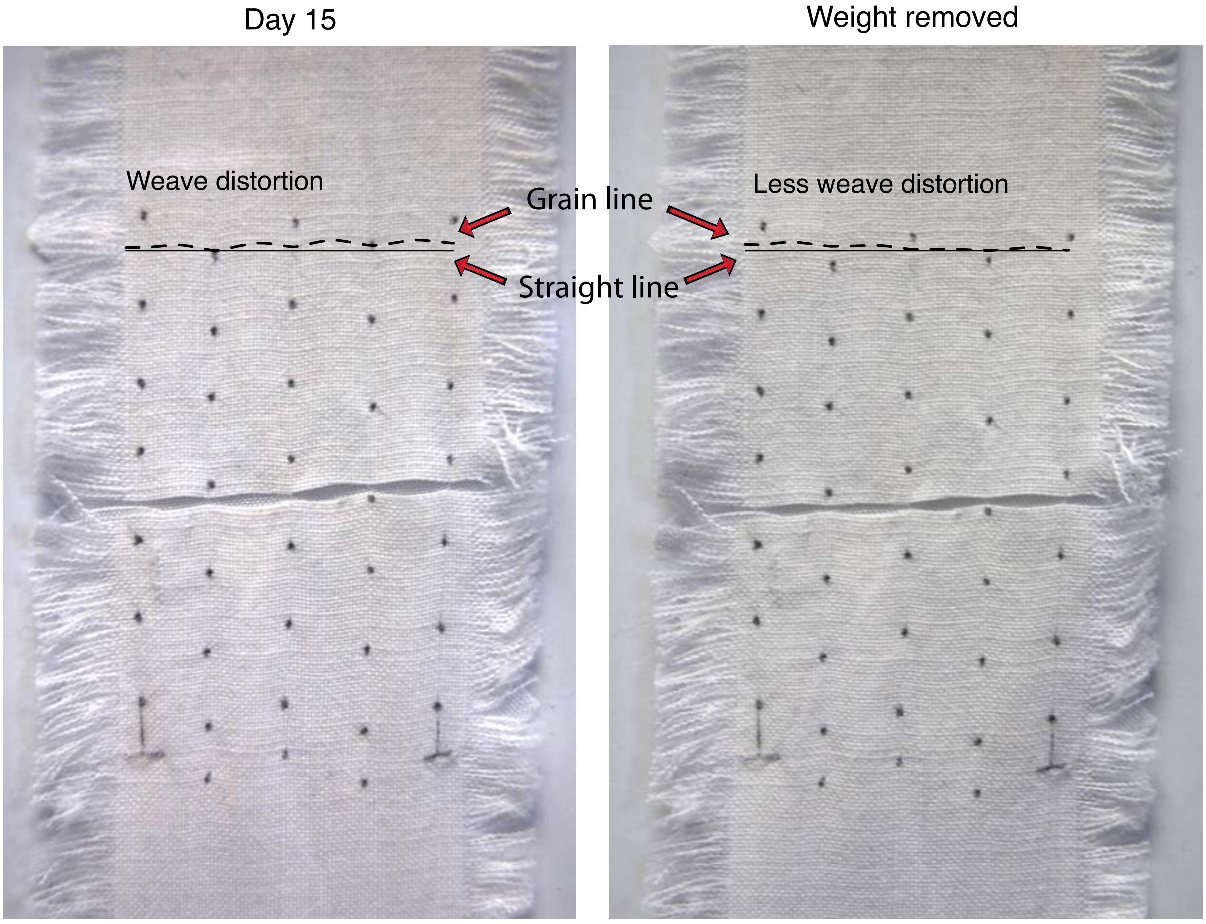

Figure 6.44: Cotton with Tetex weave distortions Left: Day 15; Right: after weights removed

Silk artefact group

Conserved silk with Tetex had the greatest maximum elongation over all the other samples with 1.30mm and a medium recovery of 0.18mm. Conserved silk with lace cotton had the greatest recovery with 0.28mm and a high maximum elongation with 1.20mm. However, as noted above, some couching rows showed more elongation than others. Silk with Skala had the lowest maximum elongation with 0.89mm and a lower recovery with 0.17mm, while silk with organsin had the lowest recovery with 0.16mm but an elongation of 0.98mm. All conserved silk samples displayed unrecoverable weave distortions that were noticeable immediately after the weight was applied. In addition, couching stitches closer to the cut edge resulted in some pulling apart of the weave (fig. 6.43 day 1). This may be attributed to the hard filament structure of the silk fabric's yarn.

Wool artefact group

Conserved wool with organsin had the greatest maximum elongation with 1.02mm and a low recovery with 0.11mm; Tetex was very similar. Wool with hair silk had the least elongation of 0.78mm but a low recovery of 0.13mm. Wool with lace cotton again had the best recovery, but with only 0.16mm which was the same as the lowest recovery seen in the silk group. Conserved wool with organsin, Skala and Tetex displayed some pulling apart of the weave by the final day and slight weave distortions were detected in samples with hair silk, organsin and Skala (fig. 6.45).

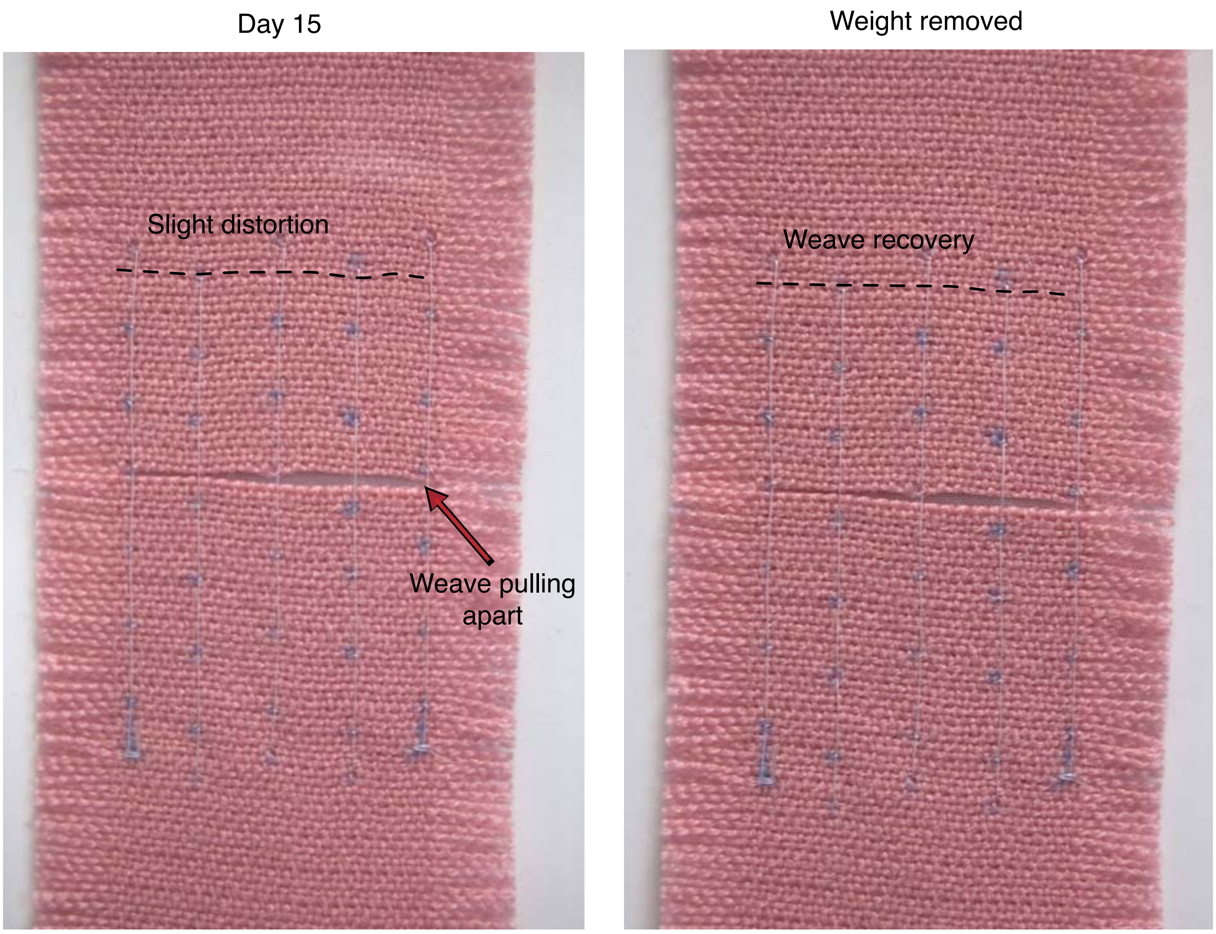

Figure 6.45: Wool with Skala slight weave damage; Left: Day 15, Right: after weights removed

6.5.4. Stereomicroscope evaluation

Microscopic evaluation after the experiment displayed more information. The magnified photos were rated against each other by type of damage seen and the degree. See Appendix 9.7 microscopic evaluation. The sample that displayed the highest degree of damage was the conserved silk with Tetex. The weft threads at the stitches were pulled downward by about 1.5 threads and had weave compression at the backstitches and cross-stitches (fig. 6.46). The samples displaying the least amount of damage were conserved cotton with organsin and conserved wool with lace cotton, hair silk and organsin (fig. 6.47). The conserved silk group exhibited the highest overall degree of damage while the wool group had the least. Although cotton displayed less damage than the silk because it showed little weave distortion, there were some samples with significant pulling down of the weft yarns and possibly some ‘cut’ fibres occurred (fig. 6.48), but this was difficult to conclude due to the staple yarn structure.

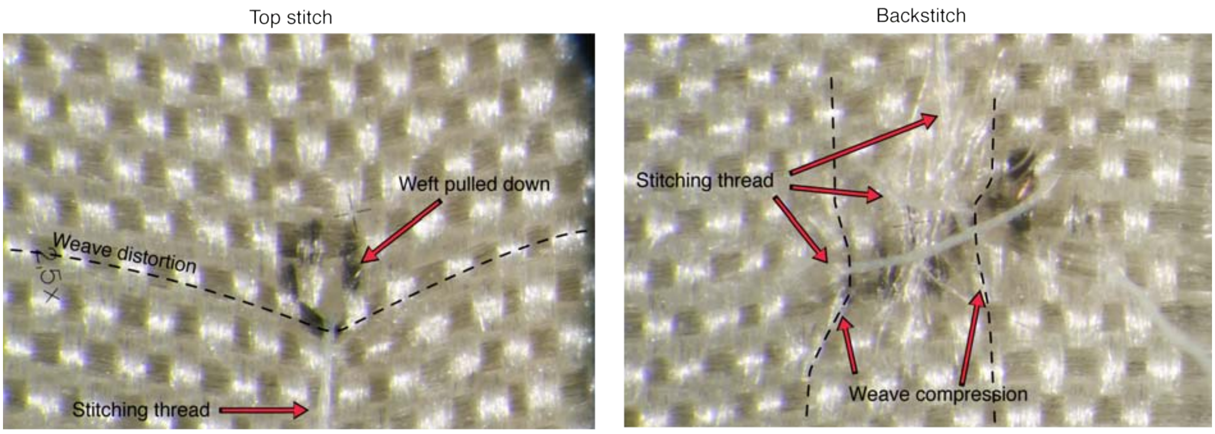

Figure 6.46: Silk with Tetex, most damage

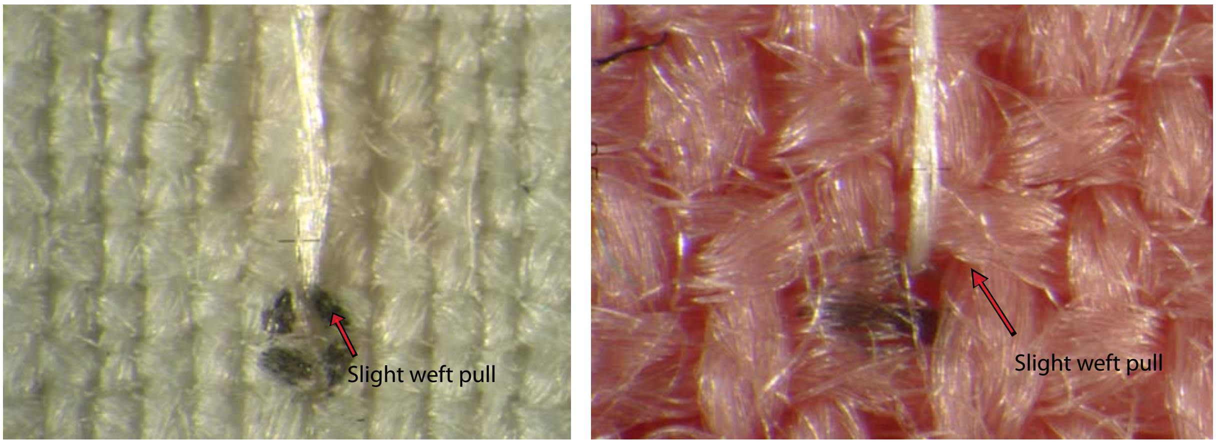

Figure 6.47: Cotton and wool with organsin, least damage

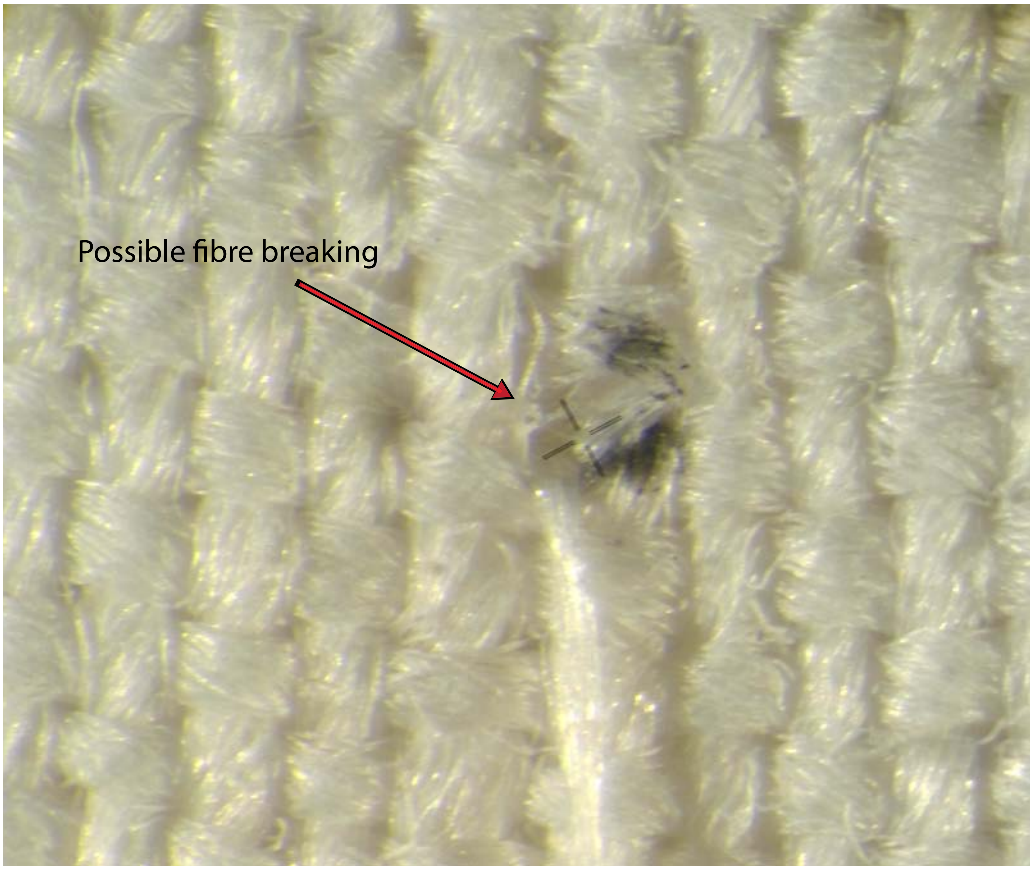

Figure 6.48: Cotton with hair silk stitch hole

Various conclusions were also observed that related to the stitching techniques. These are discussed in the next section.

6.6. Comparative discussion

Throughout the series of experiments performed, some additional conclusions were made by comparing the fixed-load with the tensile tested conserved artefact samples. The main comparisons were related to the effects of time, however, the influence of stitching techniques and the couching conservation treatment were also evaluated.

When comparing damage found in the fixed-load experiment with the tensile tested samples, it was obvious that an increased amount of time had a direct effect on the extent of damage. This was apparent even with the much lighter fixed load of 50g (equivalent force is about 0.5N) compared to the 8N applied during the tensile testing.

A ratings system that ranged from 0 to 6 was used, 6 being the highest level of damage seen and 0 being no damage (see Appendix 9.7). It should be noted that the ratings could only achieve a certain level of precision and it was done by visual analysis with the aid of computer software and only one sample of each was examined. It should also be noted that the photos were taken several days after testing and any damage seen can be considered permanent.

Using the stereomicroscope photos to compare the after damage of the fixed-load versus the tensile testing it was seen, in general, most fixed load samples displayed more damage. This was significantly evident within the conserved silk artefact groups (figs. 6.49). All the conserved silk samples exhibited more damage with the fixed-load, which was also the case with the conserved wool samples. However, the wool displayed a very minimal extent of damage in both the fixed-load and tensile testing (fig. 6.50). Conserved cotton groups had ratings much the same to each other, except for cotton with organsin in which the tensile tested sample had slightly more damage and the cotton with Skala in which the fixed-load exhibited slightly more damage (figs 6.51 and 6.52).

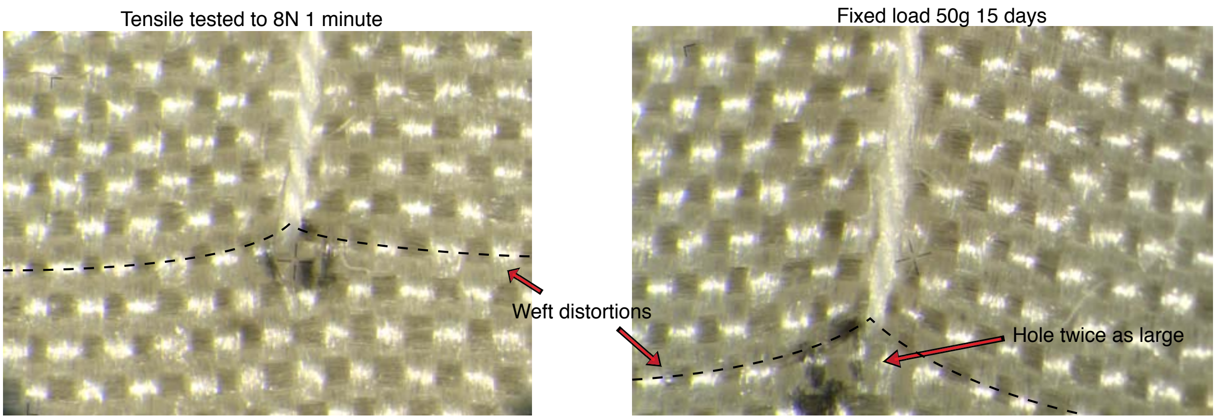

Figure 6.49: Silk with lace cotton after testing. Left: tensile tested rating of 1; Right: fixed-load rating 5

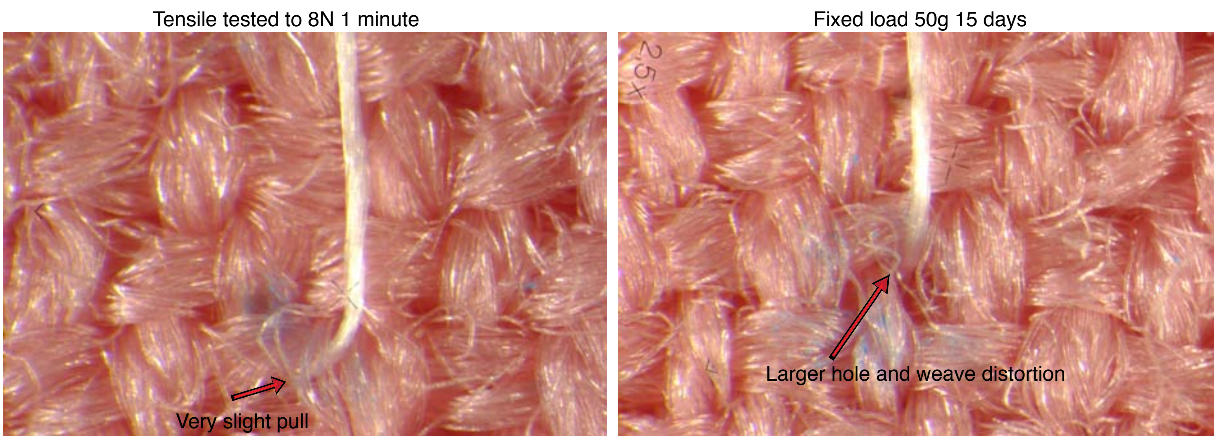

Figure 6.50: Wool with Skala after testing. Left: tensile tested rating <1; Right: fixed-load rating 2

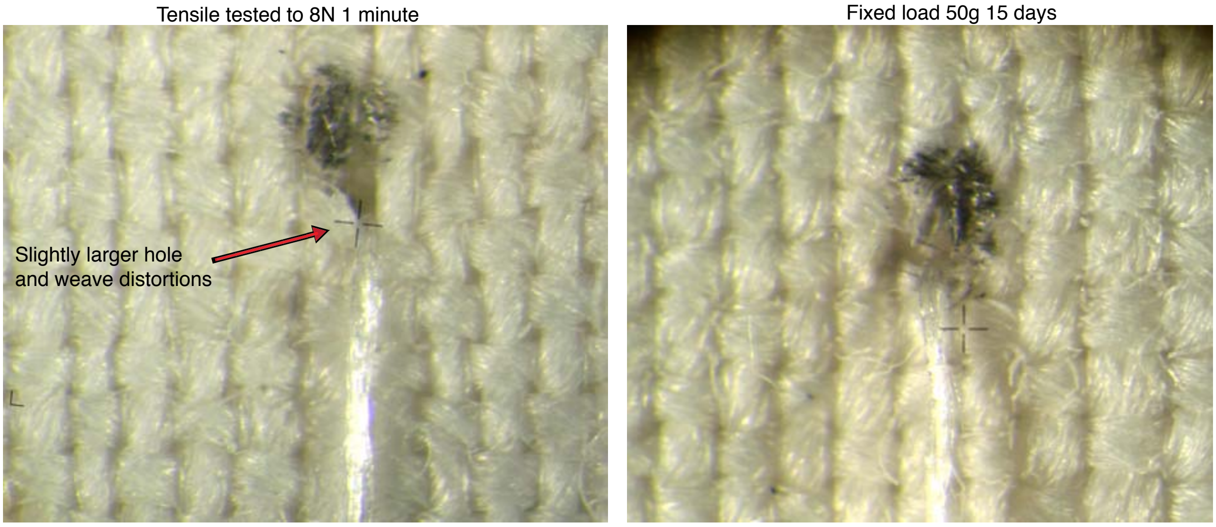

Figure 6.51: Cotton with organsin after testing. Left: tensile tested rating 2 and Right: fixed-load rating 1

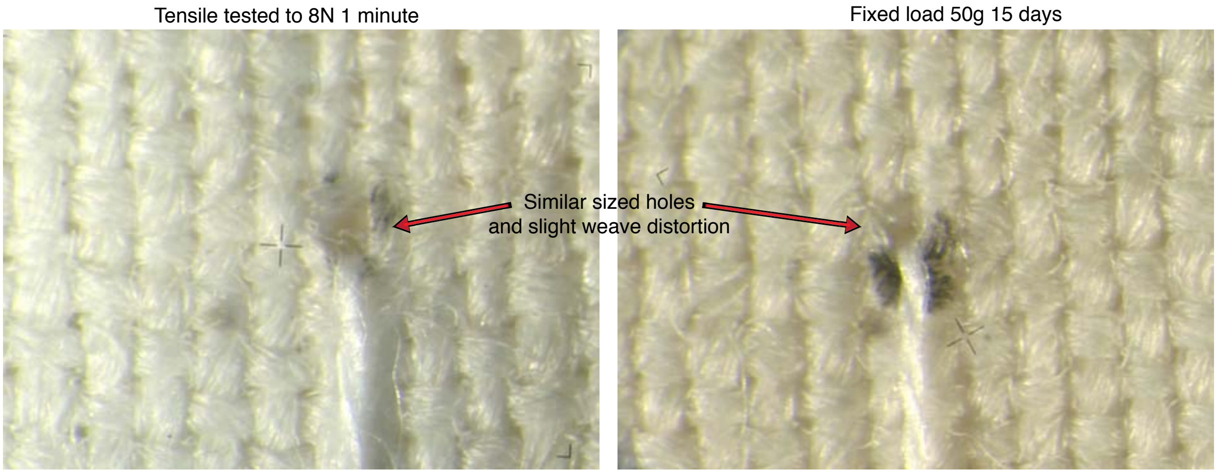

Figure 6.52: Cotton with lace cotton after testing. Left: tensile tested and Right: fixed-load both rating 2

6.6.1. <u>Stitching techniques</u>

The stitching techniques as well as the rows of couching (stitching layout) influenced the types of damage observed. The couching rows directly affected the weave structure, seen clearly in the conserved silk group in which the couching rows created uneven tension and resulted in scallop shaped deformations (fig. 6.41 pp. 81). This may have been avoided with the addition of horizontal stitching across the ends of the couching, such as herringbone stitching used to secure the patch support edges. Maintaining even tension while stitching with certain threads was more difficult, especially the hair silk as it had a hard structure that made the threads sit away from the fabrics, resulting in looser stitch tensions and producing higher elongation results.

There were a few varieties in stitching technique, even though a template and directions were used, as is expected with the nature of sewing by hand and by different people. Several observations were made that affected the damage to the samples:

- A diagonal cross-stitch caused more distortions and pulled the weave more than a straight one (fig. 6.53).

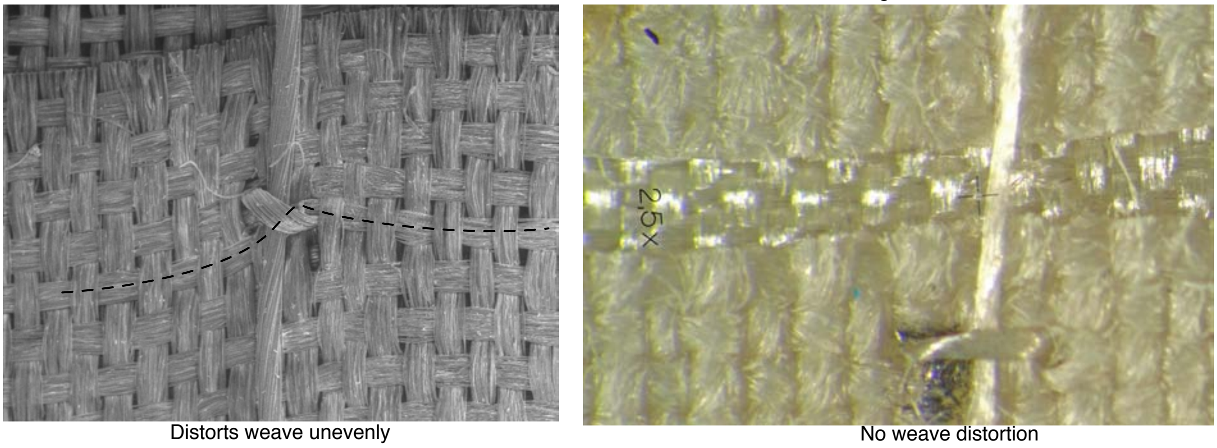

Figure 6.53: Cross-stitch: silk with Skala and Cotton with Skala after testing

- A slightly larger cross-stitch caused less weave damage by compression than a very short one (fig. 6.54).

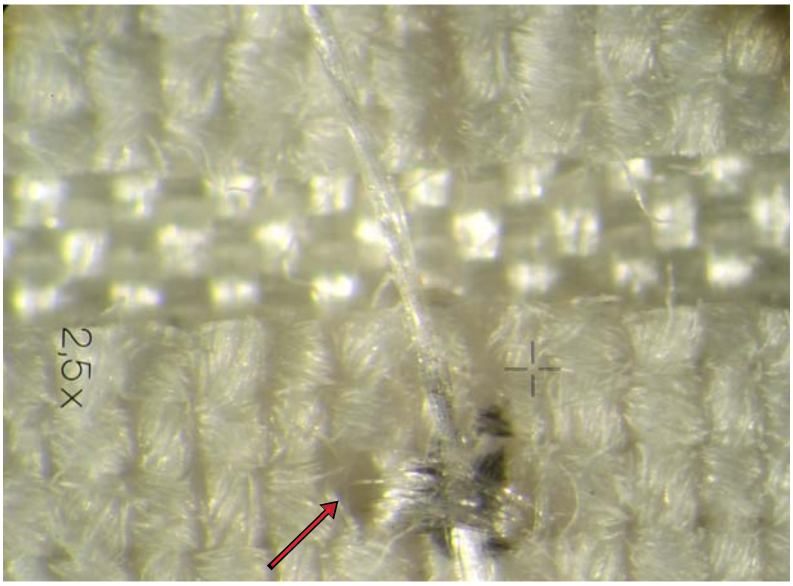

Figure 6.54: Short cross-stitch: cotton with organsin after testing

- In general, it was not possible to stitch in between the weave structure, even on the wools' loosely woven structure. In some cases, less damage was caused if the stitch went through the middle of the yarn opposed to just a small amount or between the weave (fig. 6.55).

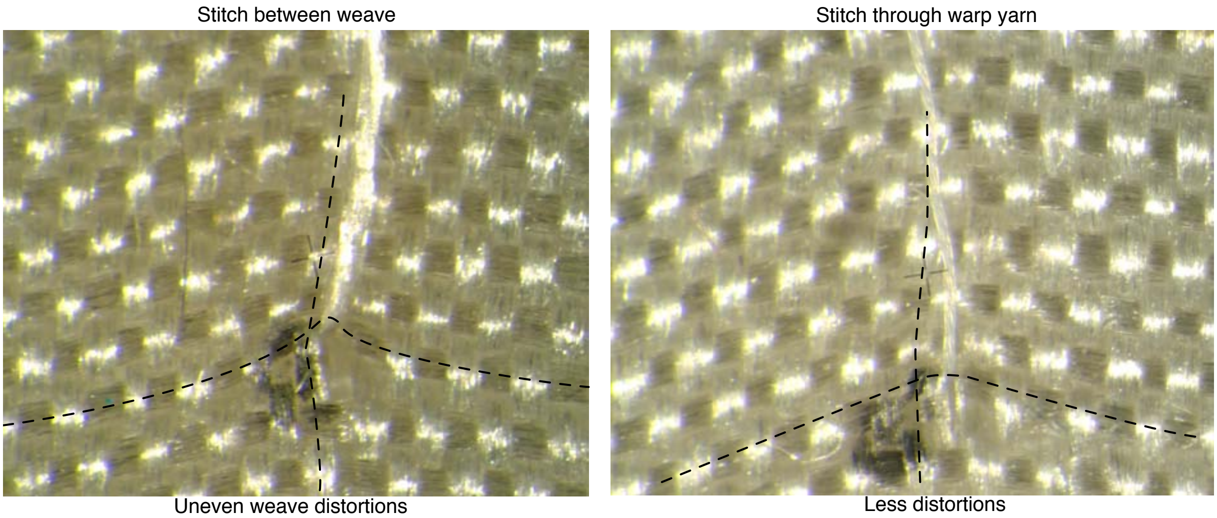

Figure 6.55: Stitch placement: silk with organsin and silk with Tetex after testing

- On a backstitch start and finish, more damage was caused if the stitches went through the same point than if they were staggered slightly (fig. 6.56).

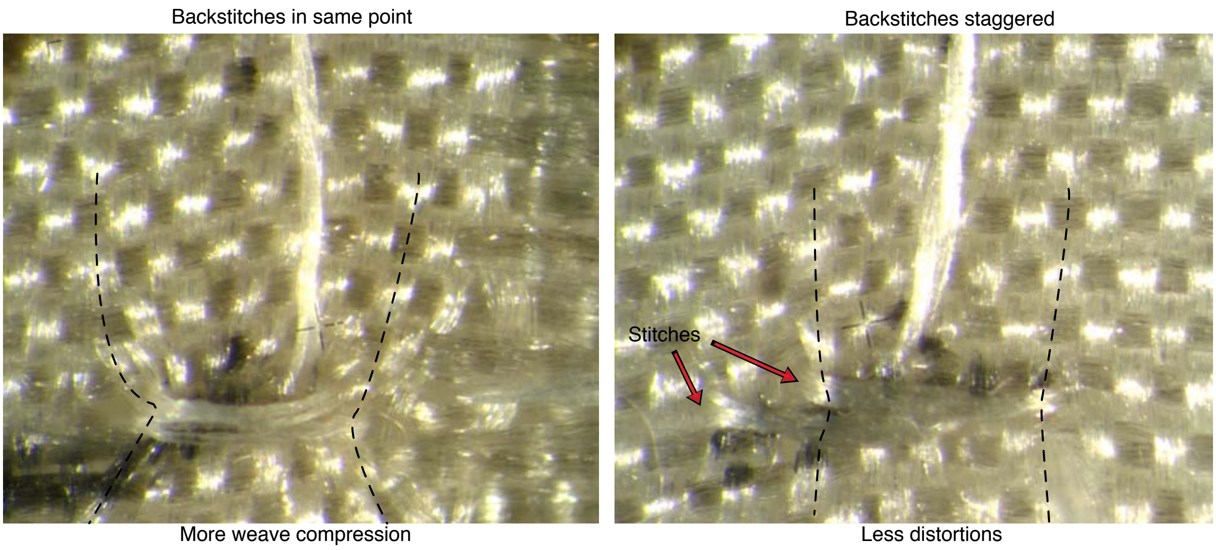

Figure 6.56: Backstitch: silk with hair silk and silk with organsin after testing

Further experimentation into the stitching types and their effects is necessary in order to conclude on the treatment with the least amount of damage and to quantify the observations seen in this section.

7. Chapter 7. Conclusion

This research set out to compare a selection of natural and synthetic fibre stitching threads commonly used in textile conservation. The aim was to better conceptualise the relationship between the stitching threads and conserved natural fibre artefact samples. This was done by evaluating if and what forms of damage the threads caused to the artefacts following the experiments. The literature review confirmed that there was a definitive lack of available conservation literature on this subject highlighting a need for research in this area. This dissertation research sought to answer three questions within the subject:

1. Can the point of damage on an artefact be determined through tensile strength testing, and if so what is it and is it consistent between the different samples?
2. What is the most appropriate thread type for natural fibre artefacts, and can this be objectively determined?
3. Can the 'like with like' theory related to threads in conservation be proved or disproved by mechanical strength testing and how does this research contribute to the debate?

7.1. Review of research questions

1. Though tensile strength testing may allow the determination of the yield point for an artefact fabric, when tested in combination with conservation materials (thread and support patch), the yield point is no longer determinable. The artefact samples have undergone damage and it is not possible to associate the point of damage with the yield point. Visual observation of the samples while undergoing tensile testing is the best way as yet to estimate a point of damage in relation to the load in Newtons. However, as determined by the fixed-load testing, the point of damage is more affected by the length of time of loading as opposed to the load amount. In addition, the level of degradation and subsequent weakening of each artefact sample in combination with the weave and yarn structure will result in different points of damage.

2. Based on the literature review and the questionnaire responses, the more desirable thread qualities for use in conservation may be considered as: a thread with moderate strength which breaks before damaging the artefact, enough elongation properties to hold the stitching repair in place while not allowing the artefact to stretch and form new damage within its structure, and good elastic recovery as replacing stitching threads after they have been extended past their elastic state is very time consuming, damaging and costly.

Aesthetic discretion qualities and ageing properties were also noted, but were outside the scope of this research.

The experiments performed gave the following conclusions about the tested threads:

- Lace cotton: has low tenacity with good structural stability which was enough to keep the conservation stitching from elongating as far as some of the other threads. Its staple structure allowed some absorption of the load and gave fairly good recovery. Though damage to the artefact base occurred, it had some of the lowest damage ratings. Tensions were easy to maintain when stitching.
- Hair silk: gave good strength and elastic recovery through the single-strand method, however it had some of the highest elongation results on the conserved samples due to difficulty in maintaining even stitching tension. It also had some of the higher damage ratings to the artefacts implying that its structure was not able to absorb stress before the artefact.
- Organsin: proved to be the overall weakest thread tested, but had fair elongation qualities. Probably due to its weakness it gave some of the lowest damage ratings, however, some damage still occurred. It was a soft thread and easier to stitch with than hair silk. The thread was permanently damaged by a lighter load and did not fully recover.
- Skala: was by far the strongest thread tested with high elongation as well. It presented better recovery than Tetex, but was still permanently damaged by a light load. It should be noted that if an artefact is likely to be placed under a large amount of stress, Skala will cause some of the highest degrees of damage as seen by the conserved new samples tensile tested to breakpoint.
- Tetex: had by far the highest elongation properties with very low strength. It was easily damaged by any load with poor recovery and no longer provided adequate support to the conserved artefact. It also had the highest degrees of damage through both the fixed-load and tensile testing. Therefore, Tetex is the least appropriate thread tested for these natural fibre artefacts.

Considering the threads tested and desired qualities, lace cotton and hair silk gave the best results. It was determined that the staple fibre structure of the lace cotton gave the thread many desirable results, however, it was one of the most noticeable threads. From performing this series of experiments, the author would recommend using fine natural fibre threads on natural fibre artefacts. However, further testing of different types of threads or sourcing other options would add to the findings.

Organsin and Tetex may only be appropriate for an artefact never to be placed under stress, as both threads have poor elastic recovery even after a small load and Tetex creates a lot of damage to the artefact.

It should be noted that for some of the damage observed, the stitching technique was more accountable than the thread itself.

3. Like with like was represented by the lace cotton thread on the cotton artefact and the hair silk and organsin on the silk artefact. The test results did not determine that like with like is more appropriate than the other fibres on natural artefacts. However, the polyester threads tested showed some undesirable qualities on these natural fibre artefacts. Most notable was the high amount of damage caused by Tetex threads and their poor elastic recovery capabilities. The literature review and questionnaire determined that conservators have chosen Tetex or similar fine polyester filament threads for treatments requiring weaker threads and more delicate properties over threads such as Skala. However, this research revealed that the high elongation properties of Tetex, regardless of its weakness, allows the thread to continue elongating placing more damaging pressure on the artefact.

This research has shown that the like with like debate is not as important as the physical structure of the threads used in conservation. The layout and technique of the stitching treatment also has more impact on minimising the damage than the chemical makeup of the stitching threads.

7.2. Key research findings

Many useful findings resulted from this research and the highlights of these are summarised below:

- In general no preference for either natural or synthetic threads was shown through the questionnaire
    - Continental Europe was an exception preferring natural fibres
- Fixed-load and tensile testing comparison determined:
    - Time is more damaging than the amount of load
        - Most artefacts on exhibit are placed under enough stress to result in damage from their own weight
- The theory that the thread should break before the artefact was not supported
- Artefact material affects damage type and the severity
- Stitching techniques and layouts affect damage types and the severity
- Threads' different physical properties are more important than chemical makeup
    - Filament or staple yarn structure has more effect on overall properties and damage

- Skala and Tetex's early yield points results in permanent damage and poor elastic recovery

7.3. Research evaluation

The methodology used resulted in an analytically strong experiment. With most tests performed, the use of statistics and replicates resulted in important numerical results that may be used in the future for accurate replication. The pretesting of the threads and fabrics gave valuable results that were used to conceptualise the tensile testing of the composite conserved artefact samples.

As with many research projects, some improvements could be made when conducting similar research:

- Elimination of the uncontrolled environment variable. Previous research and experiments have shown that environmental factors affect fabric and yarn tensile properties, especially RH as discussed by Ballard.[96]
- Stitching by hand variable, where exact reproducibility is not possible. Although control of this variable was attempted, future studies may be able to improve the method.
- More test samples to trial, allowing more accuracy when defining the process and all test groups to be testing to the same load.
- Testing a larger sample size would give higher statistically viable results including: lower standard deviations, higher rates of reproducibility, definitive results and providing a more representative picture of the data.

7.4. Recommendations for further research

Due to the complex nature of the subject, this dissertation strived to be a starting point to determine the relationship of different thread types to natural fibre artefact types on a much more delicate scale than tapestries as seen in previous studies including Asai (2008)[97]. Stitching treatments are a very common practice used by all textile conservators and yet quantifiable data is lacking on material and technique choice. Therefore, explorations in the following future research strategies can provide more answers within the subject:

- Further analysis of damage caused by stitching techniques (section 6.6) including:
  - Stitching quality or technique
  - Types of stitching
  - Different stitching layouts
  - Development of a quantitative analysis technique for damage observed

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[96] Ballard, 667-669.

[97] Asai.

- Testing different threads
  - For example, Mara (a staple polyester) which the questionnaire determined many conservators prefer over Skala
- Testing different thread variables
  - Dyes, ageing (both natural and artificial), and different environmental effects
- Testing different artefact base materials
  - Other weave, yarn and fibre types including synthetics and varying degrees of degradation
- Testing different support fabrics and combinations with artefact bases
  - A more structurally stable fabric might prevent more damage
- Testing of different time lengths in statistically verifiable experiments
- Strain mapping of conserved samples
  - Determining stitch layouts and thread types resulting in least amount of strain

7.5. Overall summary

This research has provided quantifiable data to a subject area that previously relied upon subjective opinions. In addition, many observations made in this work can influence how textile conservators will chose their stitching threads, perform their stitched treatments, and evaluate past treatments with the goal of accomplishing a successful conservation treatment which provides support to the irreplaceable artefacts without instigating new damage.

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9. Appendices

9.1. The questionnaire

Thread Type Questionnaire

For master's dissertation: MPhil in Textile Conservation, Glasgow

Sarah Benson

The final dissertation will be publicly accessible.

Name (will remain anonymous):

Position:

Institution:

Address:

This dissertation will attain quantitative data on the different threads used in textile conservation through tensile strength testing and high magnification photography to determine any damage caused by the different threads.

For the purpose of this questionnaire, laid couching is referred to as a straight laid thread in line with either the warp or weft, that is then stitched in place with perpendicular stitches placed at regular intervals.

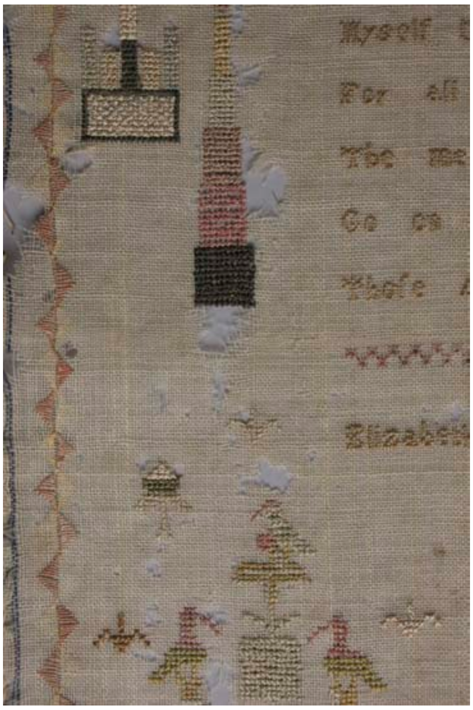
1. What threads does your institution use for laid couching treatments?

2. Would you say you generally prefer 1. natural materials when treating objects over synthetics, 2. synthetics over natural materials, or 3. no preference?

1.________ 2.________ 3.________

3. What are your reasons for using (or not using) these threads?

4. If you were given this object to treat, which thread type would you likely chose for the laid couching and why? It is a 19th century wool sampler and is to be backed with a cotton support fabric.



Note: I would be very grateful if you could provide your source for the threads you use so they may be included in the materials resource list.

This data is being collected as part of a research project concerned with the various threads used in textile conservation to determine if synthetic or natural fibre threads are more appropriate for natural fibre artefacts. The project is being carried out within the Department of History of Art, Centre for Textile Conservation of the University of Glasgow. The information that you supply and that may be collected as part of this research project will be entered into a filing system and will only be accessed by authorised persons of the University of Glasgow or its agents or its collaborators in this research project. The information will be retained by the University and will only be used for the purpose of (a) research, and (b) for statistical and audit purposes. By supplying such information you consent to the University storing the information for the stated purposes. The information is processed by the University in accordance with the provisions of the Data Protection Act 1998.

Please would you also sign the consent form below. Electronic signature is acceptable.

CONSENT TO THE USE OF DATA

University of Glasgow, College of Arts Research Ethics Committee

I understand that Sarah Benson is collecting data in the form of completed questionnaires for use in an academic research project at the University of Glasgow.

Research aims:

Establish whether there is a better thread type for particular textile artefacts

Determine this by thread type and artefact material type

I plan to research the properties and usage of the various stitching threads utilised in interventive treatments. It is thought by some conservators and countries that synthetic materials are too strong for natural fibre textiles and may cause excess damage to the artefacts. The opposing view is that the synthetics used are fine enough to give with the textile and would not cause any more damage than a natural fibre thread. Firstly, the opposing views will be researched within the literature and discussions with textile conservators to give a basis for the current level of knowledge or belief on the subject.

My approach will be through the use of testing samples of historic textiles from the Karen Finch Reference collection that have been treated with the same conservation stitches and all the different types of threads used in conservation. These samples will be tested by tensile strength and then evaluated with microscopy, possibly scanning electron microscope, to determine the levels of damage done to the threads and the textiles. From these results, it is hoped to determine a particular thread type that is best suited to a textile type which causes the least amount of damage done through force. This force should represent how a textile may behave under different forms of exhibit, such as the vertical display, or if changes in environment cause differing forces between the two materials as they absorb and desorb moisture.

I give my consent to the use of data for this purpose on the understanding that:

♣ All names and other material likely to identify individuals will be anonymised.

♣ The material will be retained in secure storage for use in future academic research

♣ The material may be used in future publications, both print and online.

Signed by the contributor:___________________________ Date:

Researcher's name and email contact: Sarah Benson 1100474B@student.gla.ac.uk
Supervisor's name and email contact: Frances Lennard Frances.Lennard@glasgow.ac.uk
Department address: 8 University Gardens; Glasgow G12 8QQ, Scotland

Please return to Sarah Benson, 1100474B@student.gla.ac.uk by May 1, 2013. Thank you very much for your participation!

9.2. The questionnaire results

Below is a summary of the compiled information received from the questionnaire responses. Similar responses were not duplicated within the same field, and was identified by the number of times similar responses were received next to the entry when important. Each section is divided according to the questionnaire questions (see Appendix 9.1).

	United Kingdom
Question 1	Skala: 13 Thicker polyesters, Gütermann: 3 Tetex: 13 Mara: 5 (more likely to use for the outer stitching) Hair silk/monofilament/Gütermann S303: 14 Lace cotton/Gütermann fine cotton: 6 Stronger cotton: 1
Question 2	Synthetics: 6 No preference: 9 Natural: 2
Question 3	Synthetics: strength and durability (uncontrolled conditions), silk threads failed: long lasting materials policy Understanding of behaviour, easy to obtain (unknown alternatives) Consider silk for smaller objects Visibility, availability, dyeable Silk preferred: polyester too strong Synthetics are hard, thick and shiny Silk, prefer like with like for same environmental reactions and visual properties Of the opinion thread should last longer than artefact, strength over time Texture: cotton more ‘grippy’ Skala can cut into the fabric Supervisor’s experiences to inform and current literature (only once) The more choice the more informed the decision, be open-minded (only once) Polyester easily identified as unoriginal stitching, has a good range. Time and cost or dying undesirable Doesn’t use Skala, too harsh and less flexible Would likely not chose cotton as too noticeable
Question 4	Tetex, fine and strong generally good colour, discreet (8) Skala or hair silk (strength and visual, tell conservation apart) (3) Silk, natural easier to stitch, not adding synthetic element, fineness wouldn’t add new holes when stitched; strong enough (7) or Tetex Skala or Mara depending appearance (2)

	United States
Question 1	DMC floss: 5 Tetex: 3 Polyester fabric: 1 Skala: 6 Cotton Mettler 50/3 or 60/2: 5 Hair silk/organsin if can find: 7 Tire silk #50 and Mettler: 3 Cotton/poly blend: 1 Cotton pulled from fabric: 1
Question 2	No preference: 7 Synthetics: 1 Natural: 3 (some indigenous groups request)
Question 3	Polyesters are inert want invisibility, objects won't be under such stresses Like with like, don't want too strong for artefact, want to degrade with artefact, not introduce more materials Synthetics last longer and now available in fine Cotton for strength and softness (larger objects) Silk easier to stitch, similar to Skala Skala too hard and unsympathetic, hair silk blends well but may also be too strong May choose Skala purely on colour match; want thread identifiable as non-original Depends on environment controls, pressure mounted, if it will bear weight Natural fibres tend to flex better with the object
Question 4	Want invisible, Tetex or finest cotton Possibly wouldn't stitch Silk or cotton (2) Silk, minimal visual doesn't need strength (2) Silk or Skala Tetex, thought fineness would weaken before sampler's fibres DMC floss, no explanation Skala (maybe just border, doesn't have expansion/contraction issues as centre of object) (2), maybe too strong but with careful stitch tension fine

	Continental Europe
Question 1	Silk (hair/organsin/Grège): 9 Cotton (170/2): 6 Skala/Gütermann: 4 Thin wool, very rarely: 2 Linen lace: 1
Question 2	Natural: 5 No preference: 3 Synthetics: 1 (Finland)
Question 3	How the material ages etc is known and will break before the object Cotton more stable than silk, silk blends with surface unlike polyester, couching doesn't require the strength, break before object Degrade with the object, dyeable, easy to stitch Choose polyester, light fast, use with robust object Cotton and silk can 'catch' to fabric, synthetics too smooth and slip
Question 4	Silk: natural fibre, strength not needed (5) Fine cotton (4), or wool (not glossy) Skala: thin, invisible and easy to stitch (1)

	Other (Australia/New Zealand and Brazil)
Question 1	Silk varieties: 4 Tetex: 3 Skala 360/polyester: 3 Embroidery cotton rarely (as infill): 1 Lace cotton: 1
Question 2	Natural: 1 No preference: 4
Question 3	Silk: soft, but degrades, dyeable, Tetex not dyeable, difficult to stitch Skala too strong Availability and properties Colours limited in synthetics, silk monofilament for very fine, matte appearance Display environment
Question 4	Silk, softest with least sheen (3) Natural, cotton if available, silk if not Or Tetex/Skala if for permanent display

*Some hair silk users specified from drawn silk crepeline

*Some specified Tetex from the weft

9.3. Material resource list

Stitching needle used:

8211 Kalt 0 from

Sutranox® Unimed CH-1002

Lausanne, Switzerland

Threads purchased for experiments:

Hair silk, 2-ply un-dyed
Talas
330 Morgan Ave.
Brooklyn, NY 11211 USA
Tel. 212.219-0770
Website: http://talasonline.com

U81 Skala™ 360 polyester thread, un-dyed
William Gee
520 Kingsland Road
London, E8 4AH, UK
Tel.: +44(0)20 7254 2451
E-mail: info@williamgee.co.uk
Website: http://williamgee.co.uk/

Egyptian Gassed Cotton 185/2 thread
Jo Firth Lacemaking and Needlecraft
58 Kent Crescent
Pudsey, West Yorkshire
LS28 9EB, UK
Tel.: +44(0)113 257 4881
Website: http://www.jofirthlacemaking.co.uk/

Organsin soie tube 1000m, silk thread
Au Ver à Soie
102, Rue Réaumur
75002 Paris
France
Tel.: +33(0)1 42 33 52 92
E-mail: info@auverasoie.fr
Website: auverasoie.com

Tetex TR (Stabiltex™), polyester fabric
Plastok Associates Ltd.
79 Market Street
Birkenhead, Wirral
CH41 6AN, UK
Tel.: +44(0)151 666 2056
E-mail: assoc@plastok.co.uk
Website: www.plastok.co.uk
*Can also get Tetex at Talas but only green is left

Sources from questionnaires:

Unfortunately many threads used are no longer in production and materials are difficult to source, but hopefully the below list will give conservators some more options.

Hair Silk and silk crepeline
Lelievre (UK) Ltd
108-110 Chelsea Harbour Design Centre
Chelsea, London SW10 0XE
Tel.: +44 20 7352 4798
E-mail: enquiries@lelievre.eu
Website: www.lelievre.eu/index.php
*Import from their French sister company

Pipers Silks
Chinnerys
Egremont Street
Glemsford, Suffolk
CO10 7SA, UK
Tel.: +44 (0) 1787 470323
E-mail: sales@pipers-silks.com
Website: http://www.pipers-silks.com

Silk monofilament
The Humphries Weaving Company Ltd
DeVere Fabrics Ltd.
Weavers House, Hyde Wood Road
Little Yeldham, Halstead, Essex
CO9 4QX, UK
Tel.: +44 (0)1787 237 237
E-mail: sales@devereyarns.co.uk
Website: www.devereyarns.co.uk

Silk crepeline
Whaleys (Bradford)
Harris Court, Great Horton
West Yorkshire, BD7 4EQ, UK
Tel. +44 (0)1274576718
E-mail: info@whaleysltd.co.uk
Website: http://www.whaleys-bradford.ltd.uk/silk-crepeline-natural

Pearsalls Embroidery
Langley threads (supply silk thread for fisherman's flies)
41 Celtic Way
Rhoose
Vale of Glamorgan
CF62 3FT, Wales
Tel.: +44 14 467 0037
Website: www.pearsallsembroidery.co.uk

Organsin de soie 2 bouts teint
Prelle
7 Rue Barodet
69004 Lyon
Tel.: +33 4 72 10 11 41
E-mail: info@prelle.com
Website: www.prelle.fr/en

Hair silk available in many shades, weaving yarn imported from France and produced in China or Brazil
Silke-Annet
Dorthesvej 2
Dk-3520 Farum, Denmark.
Tel.: 44 95 05 55
Website: www.silke-annet.dk/

Tire brand silk #50:
Superior Threads
87 East 2580 South
St. George, UT 84790 USA
Tel.: +1 435 652 1867
E-mail: info@superiorthreads.com
Website: http://www.superiorthreads.com

Cotton thread 170/2 (pre-thread taken out of the production of regular cotton-sewing threads on bobbins, to be dyed by conservator). Produced by Nef, St. Gallen.
Sänger Leinen
CH-3550 Langnau im Emmental,
3550, Switzerland
Tel.: +41 (34) 4021083
*ask for Mr. Vetsch, mention that the thread is used for conservation-restoration

Variety of fine threads, cotton and linen
Rolande de Liever
Rue St Georges, 10
B-5380 Hemptine-Fernelmont Belgium
Tel.: +33 081 855 579
E-mail: deliever-rol@deliever.com
Website: www.rolande-deliever.com

Fine lacemaking threads, especially cotton
Centre d'Enseignement de la Dentelle au Fuseau
38 à 44 rue Raphaël
43000, Le Puy-en-Velay, France
Tel.: +33 4 71 02 01 68
E-mail:
enseignement@ladentelledupuy.com
Website: www.ladentelledupuy.com

Coats plc UK Thread
Suites R-S
Lingfield House
Lingfield Point
McMullen Road
Darlington, Co. Durham DL1 17J, UK
Tel.: +44 (0) 845 603 0150
E-mail: uk@ireland.contactus@coats.com
Website: www.coats.com/index.asp

DMC® cotton 6 Strand Embroidery Floss
The Edwardian Needle
225 Belleville Avenue
Bloomfield, New Jersey, USA
Tel.: +1 973 743 9833
E-mail: info@theedwardianneedle.com
Website: www.theedwardianneedle.com

Gütermann Threads
Tony Slade @
T.S. Sewing Supplies
10 Brambles Road
Burnham-on-Sea
Somerset, TA8 2PY, UK
Tel: +44 (0) 1278 786378
E-mail: tonyslade101@btinternet.com

Gütermann Threads
Testfabrics, Inc.
415 Delaware Ave
West Pittston PA 18643 USA
Tel: +1 (570) 603 0432
E-mail: info@testfabrics.com
Website: www.testfabrics.com

Polyester threads
MacCullloch & Wallis
25-26 Dering Street
London, W1S 1AT, UK
Tel.: +44 020 7629 0311
E-mail: mailorder@macculloch.com
Website: www.macculloch-wallis.co.uk

Tetex® manufacturers:
Headquarters
Sefar AG®
Hinterbissaustrasse 12 9410
Heiden, Switzerland
Tel.: +41 71 898 57 00
E-mail: filtration@sefar.com
Website: www.sefar.com
*Regional divisions as well

9.4. Stitching instructions

Directions for preparing conserved samples:

1. Cut at least 60cm long strand of the thread using
2. Cut the artefact on the marked halfway line
3. Align the cut line with the centre of the silk support patch (pinked and cut to about 55mm long)
4. Pin the patch in place with fine pins avoiding the stitching area
5. Using an 8211 Kalt 0 curved needle, begin stitching on the bottom left side with three backstitches (three inserts of the needle) horizontal to the couching line and no more than 3mm wide
6. The couching stitches need to be exactly where marked and perpendicular. Make the cross stitch of the couching just wide enough to hold the thread (no more than 1mm wide)
   - 6.1. Stitch all cross stitches from right to left
   - 6.2. Maintain even tension, and check to be sure the threads are laying flat on the backside
7. Finish the last stitch in the same manner as step 5
8. Trim the thread ends to about 3mm leaving a short tail
9. Fray the long edges up to the marked point giving a finished width of 25mm ±0.5mm

Sample number code:

1 = Lace cotton; 2 = Hair silk; 3 = Organsin; 4 = Skala; 5 = Tetex (Stabiltex)

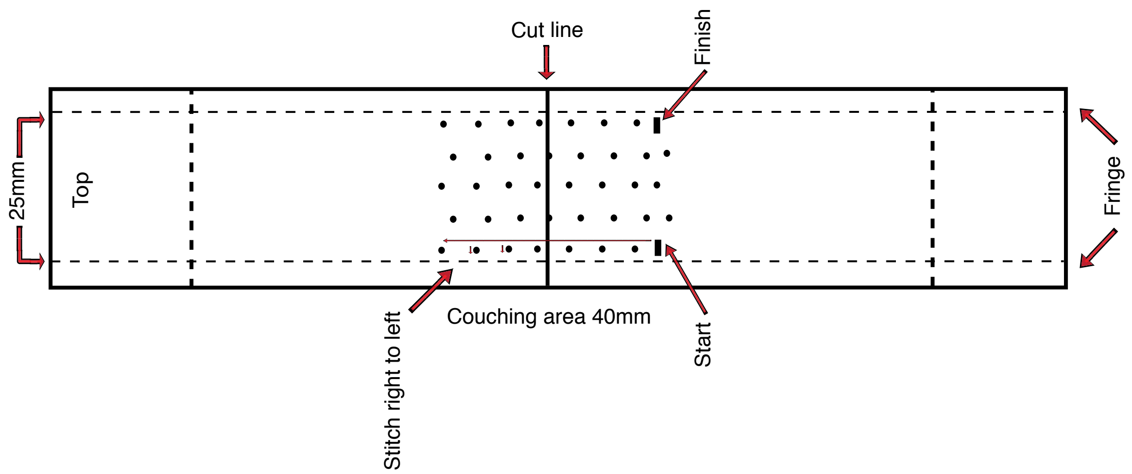
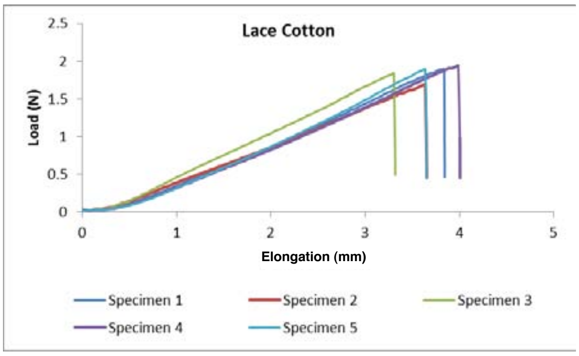


Figure: Stitching process

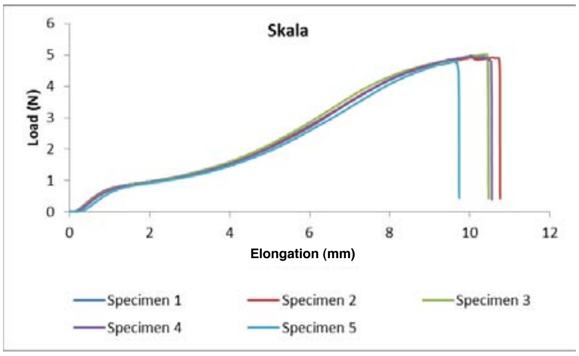
9.1. Tensile strength testing graphs

Below are the Load vs Elongation graphs for all elements tests including each specimen.

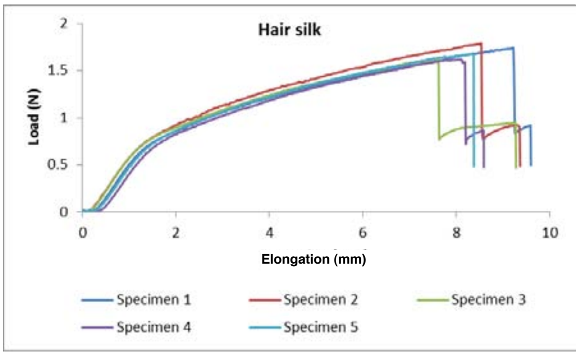
Threads:



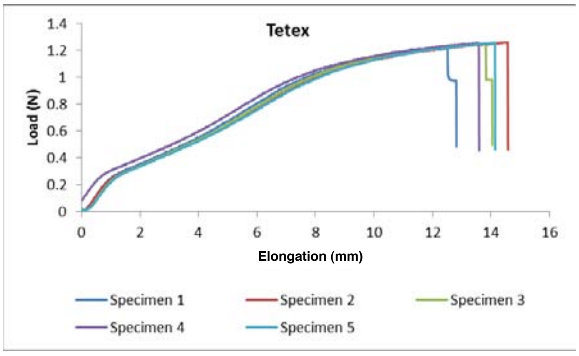
Maximum load mean: 1.85228
Standard deviation: 0.09580 N
Maximum elongation mean: 3.68016
Standard deviation: 0.25717 mm



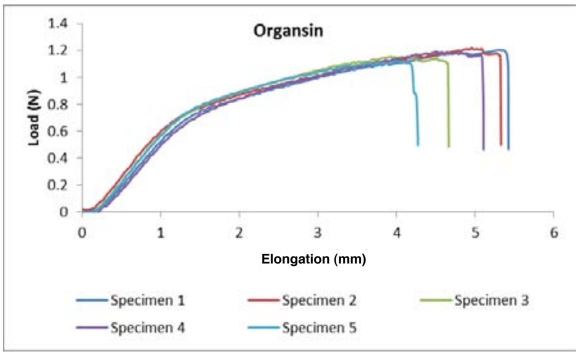
Maximum load mean: 4.93856
Standard deviation: 0.08945 N
Maximum elongation mean: 10.07611
Standard deviation: 0.29455 mm



Maximum load mean: 1.69050
Standard deviation: 0.07605 N
Maximum elongation mean: 8.35336
Standard deviation: 0.59518 mm

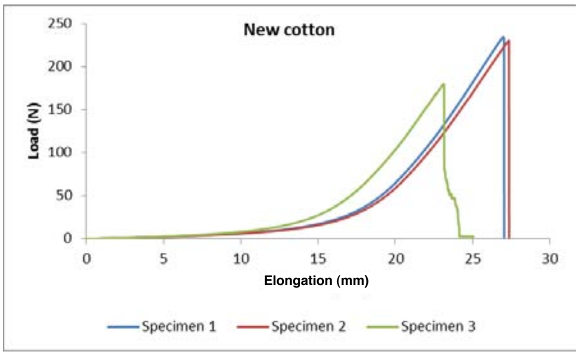


Maximum load mean: 1.25057
Standard deviation: 0.01235 N
Maximum elongation mean: 13.69152
Standard deviation: 0.78745 mm

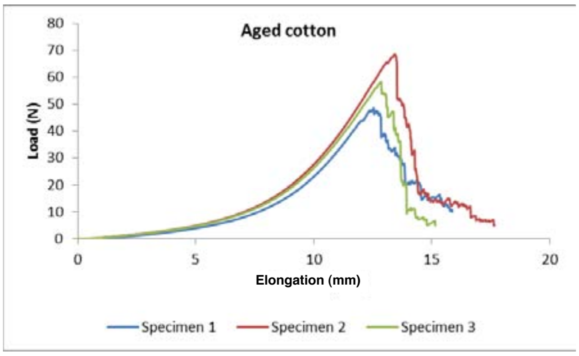


Maximum load mean: 1.17814
Standard deviation: 0.03909 N
Maximum elongation mean: 4.53678
Standard deviation: 0.59748 mm

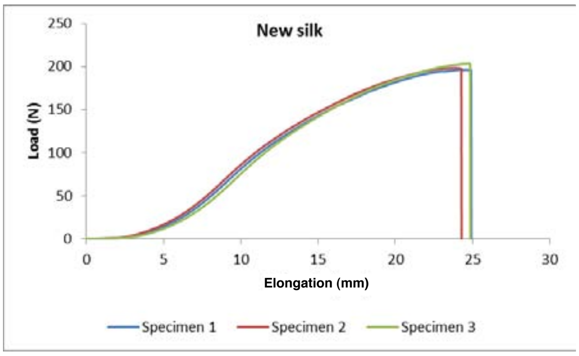
Fabrics:



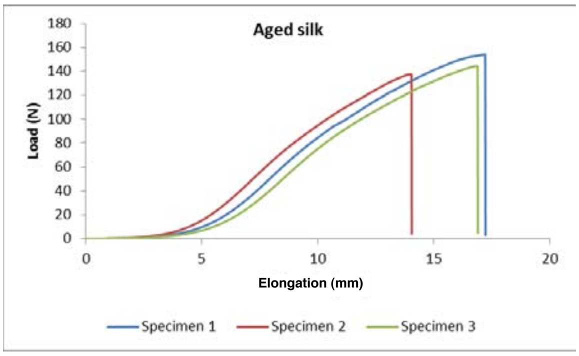
Maximum load mean: 214.70
Standard deviation: 30.33450 N
Maximum elongation mean: 25.82
Standard deviation: 2.34795 mm



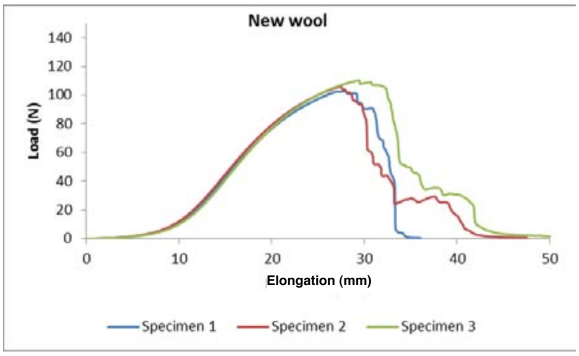
Maximum load mean: 58.47
Standard deviation: 10.02660 N
Maximum elongation mean: 12.94
Standard deviation: 0.46116 mm



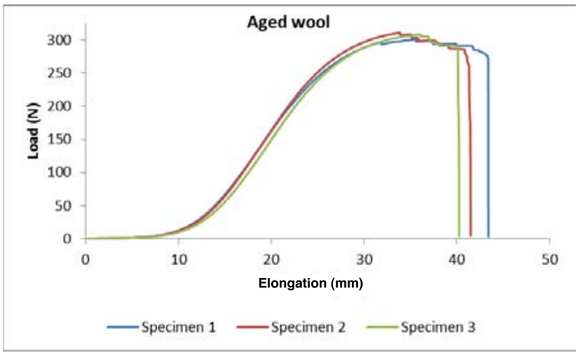
Maximum load mean: 199.27
Standard deviation: 3.65473 N
Maximum elongation mean: 24.31
Standard deviation: 0.45762 mm



Maximum load mean: 145.29
Standard deviation: 8.43725 N
Maximum elongation mean: 15.98
Standard deviation: 1.78036 mm

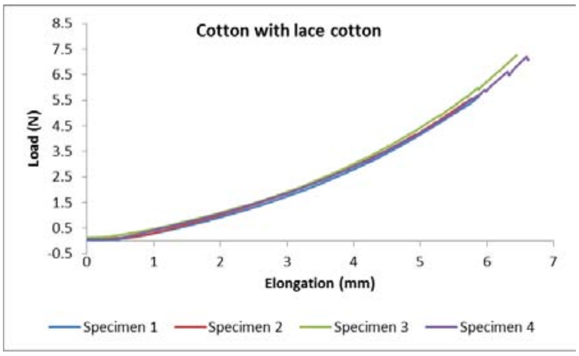


Maximum load mean: 106.32
Standard deviation: 3.81504 N
Maximum elongation mean: 28.26
Standard deviation: 1.03042 mm

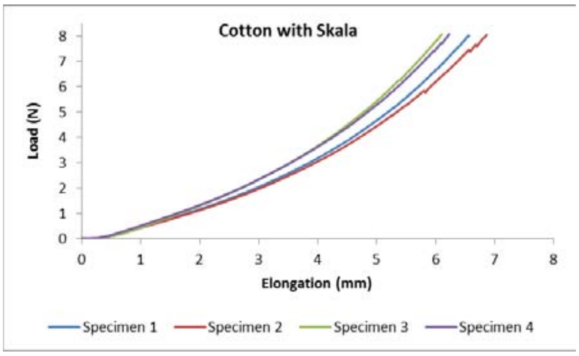


Maximum load mean: 306.80
Standard deviation: 5.05885 N
Maximum elongation mean: 35.15
Standard deviation: 1.15742 mm

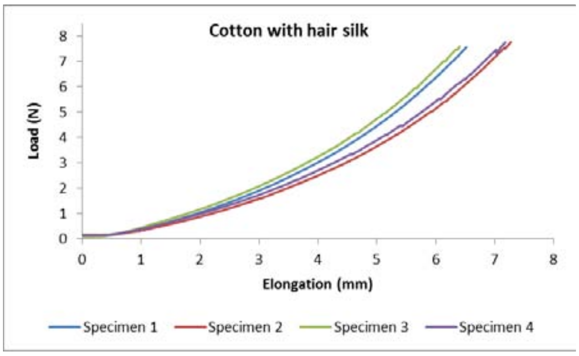
Conserved artefact samples (to 8N):



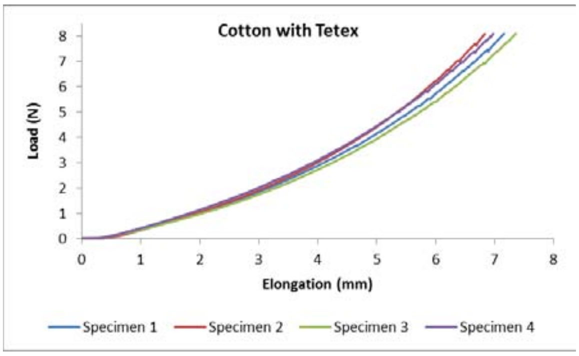
Maximum load mean: 6.44
Standard deviation: 0.91195 N
Maximum elongation mean: 6.19
Standard deviation: 0.38527 mm



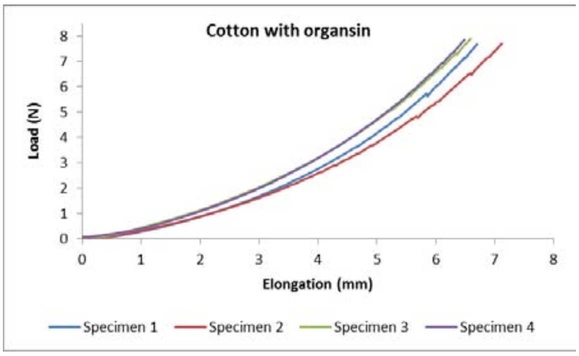
Maximum load mean: 8.06
Standard deviation: 0.02559 N
Maximum elongation mean: 6.44
Standard deviation: 0.34304 mm



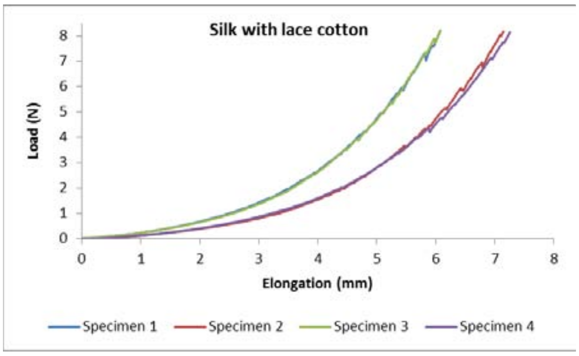
Maximum load mean: 7.76
Standard deviation: 0.10829 N
Maximum elongation mean: 6.84
Standard deviation: 0.44587 mm



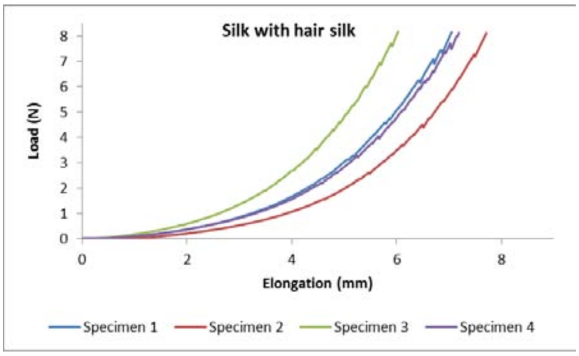
Maximum load mean: 8.10
Standard deviation: 0.00508 N
Maximum elongation mean: 7.08
Standard deviation: 0.22726 mm



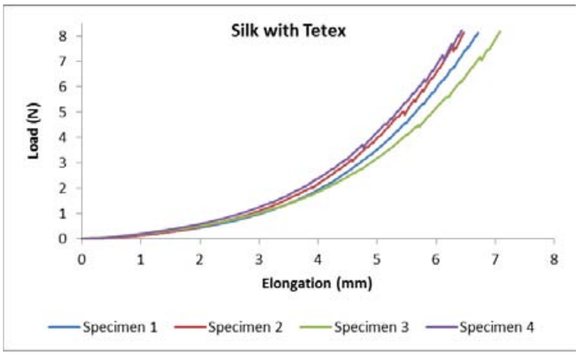
Maximum load mean: 7.79
Standard deviation: 0.11048 N
Maximum elongation mean: 6.72
Standard deviation: 0.27675 mm



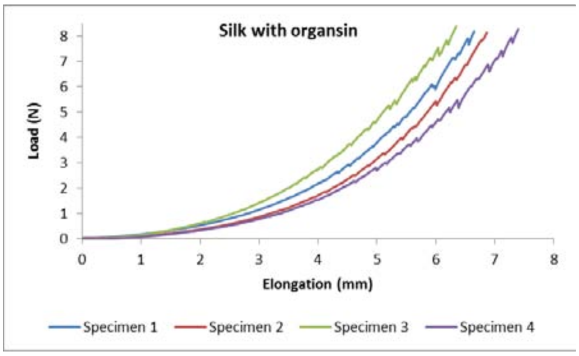
Maximum load mean: 8.19
Standard deviation: 0.03135 N
Maximum elongation mean: 6.64
Standard deviation: 0.65086 mm



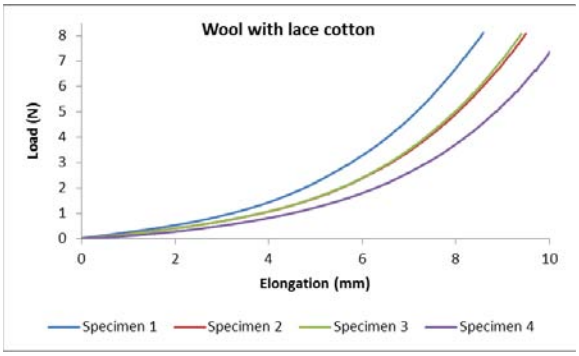
Maximum load mean: 8.15
Standard deviation: 0.02860 N
Maximum elongation mean: 7.00
Standard deviation: 0.70519 mm



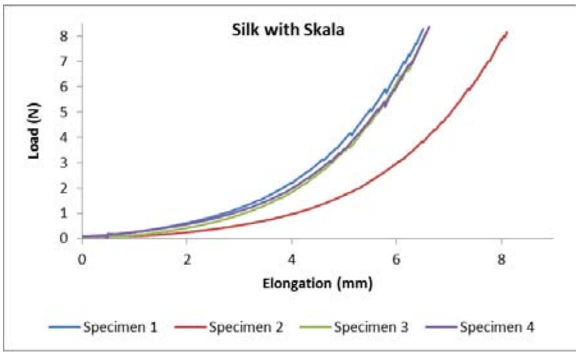
Maximum load mean: 8.17
Standard deviation: 0.05019 N
Maximum elongation mean: 6.67
Standard deviation: 0.29828 mm



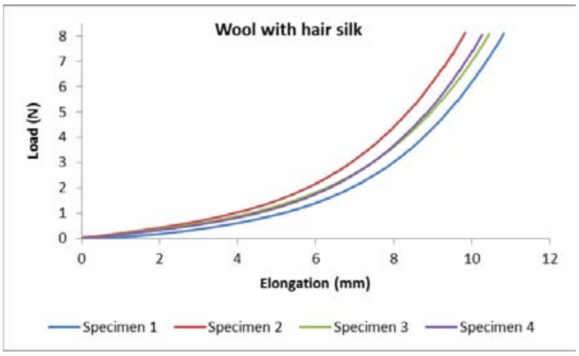
Maximum load mean: 8.25
Standard deviation: 0.11694 N
Maximum elongation mean: 6.81
Standard deviation: 0.44268 mm



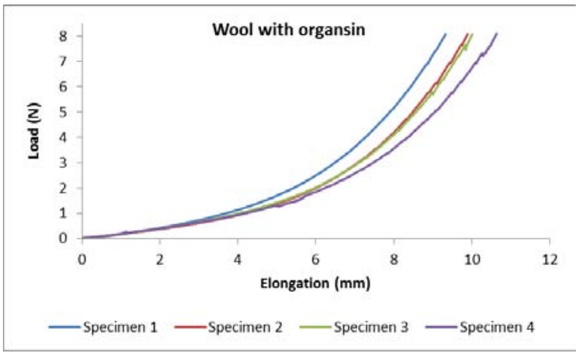
Maximum load mean: 8.10
Standard deviation: 0.01338 N
Maximum elongation mean: 9.44
Standard deviation: 0.69974 mm



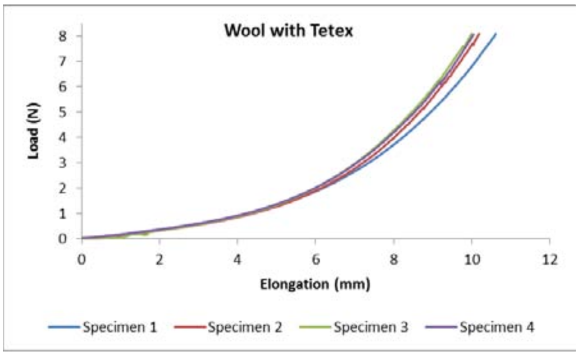
Maximum load mean: 8.23
Standard deviation: 0.11579 N
Maximum elongation mean: 6.95
Standard deviation: 0.77418 mm



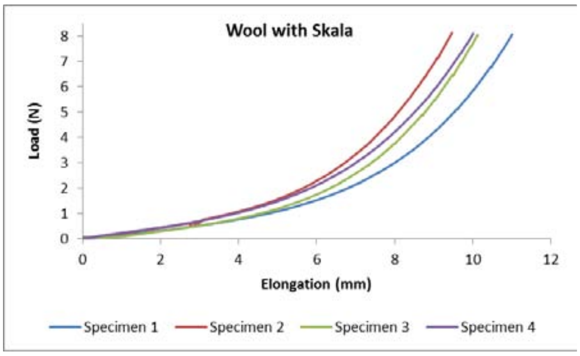
Maximum load mean: 8.10
Standard deviation: 0.02761 N
Maximum elongation mean: 10.34
Standard deviation: 0.41186 mm



Maximum load mean: 8.09
Standard deviation: 0.00979 N
Maximum elongation mean: 9.97
Standard deviation: 0.53809 mm



Maximum load mean: 8.09
Standard deviation: 0.01846 N
Maximum elongation mean: 10.21
Standard deviation: 0.27932 mm



Maximum load mean: 8.09
Standard deviation: 0.03594 N
Maximum elongation mean: 10.15
Standard deviation: 0.63898 mm

9.2. Fixed-load measurements

These measurements (all in mm) were achieved by photographs taken on the below days and a measurement tool in Adobe Illustrator was used to give elongation measurements of the largest gap between the cut line on the conserved samples. The numbers are only representative of the largest gap, however, each couching row presented different amounts of elongation.

Day	Lace cotton	Hair Silk	Organsin	Skala	Tetex
With 50g weight					
Day 1	0.58mm	0.56	0.82	0.76	0.57
Day 3	0.73	0.59	0.95	0.79	0.59
Day 7	0.78	0.62	1.00	0.84	0.64
Day 11	0.82	0.66	1.00	0.88	0.64
Day 15 final	0.84	0.70	1.00	0.88	0.67
Weight removed					
Final measurement	0.57	0.59	0.91	0.69	0.53
Initial recovery	0.27	0.11	0.09	0.19	0.14

Table: Conserved cotton artefact sample

Day	Lace cotton	Hair Silk	Organsin	Skala	Tetex
With 50g weight					
Day 1	0.60	0.92	0.84	0.82	0.81
Day 3	0.74	0.97	0.88	0.85	1.10
Day 7	0.97	1.00	0.93	0.85	1.30
Day 11	1.10	1.00	0.98	0.89	1.30
Day 15 final	1.20	1.00	0.98	0.89	1.30
Weight removed					
Final measurement	0.92	0.84	0.83	0.72	1.12
Initial recovery	0.28	0.16	0.15	0.17	0.18

Table: Conserved silk artefact sample

Day	Lace cotton	Hair Silk	Organsin	Skala	Tetex
With 50g weight					
Day 1	0.56	0.59	0.85	0.44	0.72
Day 3	0.62	0.62	0.95	0.53	0.79
Day 7	0.62	0.62	0.98	0.56	0.83
Day 11	0.69	0.78	0.98	0.74	0.83
Day 15 final	0.81	0.78	1.02	0.84	0.93
Weight removed					
Final measurement	0.64	0.65	0.91	0.68	0.80
Initial recovery	0.17	0.13	0.11	0.16	0.13

Table: Conserved wool artefact sample

9.3. Microscopic evaluation: degree of damage

Evaluations were done under a stereomicroscope using one of each sample tested in both the fixed-load and tensile test to 8N experiments. The same four stitches were evaluated on each sample: the first top stitch, a stitch at the cutline, the second bottom stitch, and the final backstitch (see example photos below). All ratings were done by visual analysis by the author and though they cannot be statistically quantified, they were able to qualify the damage seen on the samples and give a comparison.

Figure: Cotton with lace cotton 4 stitches evaluated; fixed-load (rating 2)

Sample	Comments	Rating (1-6)
Cotton artefact		
Lace cotton	pulled weft down by 1 row, slight weave distortion	very few fibres broken (2)
Hair silk	slightly greater than above	half weft broken (3)
Organsin	less than above, more damage to thread	minimal (1)
Skala	same as LC, slightly more on bottom; slight compression of backstitches	weft distorted (3)
Tetex	weft pulled down 1.5 row, slight weave distortion. Backstitch compression	few fibres broken, distortion (4)
Silk artefact		
Lace cotton	weft pulled down 1, greater weave distortions than cottons	distortions (5)
Hair silk	similar above, slightly less, bad backstitch compression	distortions, compression (5)
Organsin	pulled down almost 1, bottom worse, slight compression	“ (4)

Sample	Comments	Rating (1-6)
Skala	pulled less than above, weave distortions, compression at cross stitch	" (4)
Tetex	pulled 1.5, thread very stretched, bad compression	distortions, compression (6)
Wool artefact		
Lace cotton	very slight compression	compression (1)
Hair silk	" "	compression (1)
Organsin	very slight distortion	distortions (1)
Skala	slightly greater than above with compression at backstitch	distortions, compression (2)
Tetex	thread damaged, very slight distortion and compression	distortions, compression (2)

Table: Fixed-load samples

Sample	Comments	Rating (1-6)
Cotton artefact		
Lace cotton	larger hole, slight pull down weft and compression at backstitch	2
Hair silk	possible 'cutting' of yarns, slight compression	3
Organsin	larger hole than LC, slight weft pull and compression	2
Skala	pull down by 1 weft, more even compression	2
Tetex	pull down by more than 1 weft, more compression	4
Silk artefact		
Lace cotton	very slight pull and compression at bottom, thread damaged	1

Sample	Comments	Rating (1-6)
Hair silk	very slight pull and compression (technique?), thread damaged	1
Organsin	more weave distortion and compression	3
Skala	slight pull and compression	2
Tetex	more compression and slight pull, thread damaged	3
Wool artefact		
Lace cotton	very minimal, more compression at backstitch (technique)	1
Hair silk	“ ”	1
Organsin	same as above, slightly less compression	<1
Skala	“ ”	<1
Tetex	slight more pull at bottom and compression	1

Table: Tensile tested samples

9.4. Material samples

9.5. Risk assessment

RISK ASSESSMENT FORM

School: Culture and Creative Arts	**Section:** Centre For Textile Conservation and Technical Art History	**Location:** Room number(s) 309a/b, 310, 313	**Reference No:** R20/13	**Related COSHH Form (if applicable):** C________

Description of activity:
Dissertation project, testing tenacity and damage of stitching threads used in conservation.

Using Instron 5544 tensile strength tester; preparation of samples using sharp tools

Persons at risk:
Sarah Benson, other students, supervisors

Is operator training/supervision required? If yes, please specify: Yes, training session with engineer Professor Elizabeth Tanner. Always perform tests with someone else present in the Centre.

Hazards/ Risks	Current controls	Are these adequate?	What action is required if not adequately controlled?
Trapping fingers/hands in equipment	Training in use of tensile machine, keep hands clear of equipment when in use. Do not place fingers inside instrument's grips at any time. Only use when member of staff is present in CTCAH	**Yes**	
Use of sharp tools	Blades should be covered when not in use. Always point sharp end away from user and others around	**Yes**	
Tripping/slips	Tape down extension leads, mop up any spillages.	**Yes**	

Completed by (print name and position, and sign): **Sarah Benson, 2nd year student**	**Date: 30.04.2013**
Approved by (print name and position, and sign): Frances Lennard, Senior Lecturer, Textile Conservation	**Date: 01.05.13.**