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Viscose Rayon: An Absorbing Problem. An Investigation into the Impact Conservation Wet Cleaning Treatments have on Historic Woven Viscose Rayon Fabrics; with a Supplementary Analysis of Current Techniques for Identifying Man-Made Fibres.

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1. Introduction

Viscose rayon was first invented over a century ago.[1] During this time it has been known by different generic and trade names. Its relative short existence is reflected in the minimal amount of literature available on its conservation. It is likely that viscose rayon textiles will increasingly appear at the textile conservator's workbench and therefore more research is needed, to ensure well informed treatment decisions.

This project focused on the low wet strength attributed to viscose rayon textiles and aimed to explore the appropriateness of wet cleaning as a treatment option for conservators working with this fibre by conducting a series of tensile strength tests on examples of the fibre.

This research was undertaken as part of the main author's dissertation. Testing was carried out at the Centre for Textile Conservation Centre and Technical Art History (*CTCTAH*) at the University of Glasgow.

To begin, insight into *why* viscose rayon fibres have the particular characteristic of poor wet strength is given, looking at manufacture and chemical composition, to explain the impetus for research. Details of testing and analysis of their results is then given, to show *how* this may affect conservation treatment choice.

1.1 Viscose Rayon Manufacture and its Influence on Wet Strength

The viscose process, patented in 1892, was invented by British chemists Charles Cross, Clayton Beadle and Edward Bevan.[2-3] Samuel Courtauld and Co. Ltd bought the rights to the viscose process and in 1905 began textile fibre production in their factory in Coventry, England.[4] To begin, man-made fibres were developed to replicate the desirable properties of natural silk, without its high cost, named at the time *artificial silks*.[5] Viscose rayon today is classified as a semi-synthetic regenerated cellulosic fibre; so-called as its production involves breaking-down the cellulose polymer of wood and regenerating the cellulose polymer molecular structure in filament form. R. Moncrieff explains that:

> '[…] the final filament differs chemically from the original cellulose of the wood in only one respect – that it has suffered some degradation during the manufacturing processes: the very long cellulose molecules have been partly

[1] Susannah Handley, 'Chapter 1, 1700s-1930. The Chemist Conquers the Worm', in Nylon: The Manmade Fashion Revolution, (London: Bloomsbury, 1999), p. 21.

[2] Woodings, (2001a), p. 5.

[3] Textile Mercury Annuals, (1953), p. 666.

[4] Handley, (1999), p. 21.

[5] Handley, (1999), pp. 16-17.

hydrolysed and have been broken down into shorter, although still very long, molecules.'[6]

This degradation imparts low wet strength to the fibre..

The first viscose rayon fibres from 1905 had especially low dry and wet strength.[7] Improvements made to manufacturing over proceeding years led to a one hundred percent increase in fibre strength by the 1920s,[8] although viscose rayon still had low wet strength compared with other fibres, as shown by a *Lux* washing soap advert from 1926 (Illustration. 1). Since the 1920s, progressive manufacturing modifications and the use of finishing techniques has resulted in fibres with further improved wet strength and other properties, catering for a variety of end usages.[9] In its original *natural* form viscose rayon has a silk-like appearance but advances in manufacturing have enabled it to be processed with appearance and handle similar to fibres like cotton and wool.[10] The most significant improvements to wet strength are documented as occurring in the 1920s, 1950s and 1970s.[11]

Knowledge of manufacturing changes has revealed that older examples are likely to display poorer wet properties than later examples. It was decided to contextualise this research by assessing the extent of loss in strength for wet cleaning historical woven viscose rayon fabrics with the aim of showing whether different treatment choices, based on year of manufacture, may be appropriate. A series of controlled scientific tests were conducted on specimens of viscose rayon from three eras, c.1940s, c.1960s and c.1980/90s, dated by researching fashion/textile fashions and obtained from charity shops and online auctions for this research. Their strength was measured using a tensile strength tester. . It was hoped to obtain an earlier viscose rayon object, dated 1905-1920, as fibres produced in this period had reportedly the lowest wet strength of all, but unfortunatelyexamples could not be sourced within the project timeframe.

Tensile tests aimed to show any differences between dry and wet specimens which had been subjected to a controlled wet cleaning treatment, in order to contextualise research for conservation practices. In addition, specimens were also tested which had been subjected to a controlled wet cleaning treatment and then allowed to air-dry, to show whether any changes in wet properties were permanent.

It should be noted that in addition to the scope of this research, the range of manufacturing modifications, briefly mentioned above, give rise to a diversity of fibre properties available of viscose rayon which complicate predictions for fibres behaviour during wet cleaning.

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[6] R. W. Moncrieff, 'Chapter 9 - Viscose Rayon', in *Man-Made Fibres*, (London: Butterworth & Co Ltd, 1975), p. 164.

[7] Teresa A. Summers, Billie J. Collier, John R. Collier and Janice L. Haynes, 'History of Viscose Rayon', in Raymond B. Seymour and Roger S. Porter (eds.) *Manmade Fibers: Their Origin and Development*, (Essex: Elsevier Science Publishers Ltd, 1993), p. 77.

[8] John W. S. Hearle, 'Chapter 8 – Physical Structure and Fibre Properties', in Calvin Woodings (ed.), *Regenerated Cellulosic Fibres*, (Cambridge: Woodhead Publishing in association with The Textile Institute, 2001), p. 214.

[9] Cook, (2009), p. 11.

[10] Hatch, (1993), p. 187.

[11] Kathryn L. Hatch, *Textile Science*, (St. Paul, USA: West Publishing Company, 1993), p. 186.

Therefore for conservation, it should be understood that viscose rayon may not necessarily act within a conformed XXX common format.

Figure 1 - Lux Soap Advert, 1926
From Photoplay Vol. 30, July 1926, (Chicago: Photoplay Magazine Publishing Company, 1926).

1.2 Viscose Rayon Fibre Chemistry and its Influence on Wet Strength

When regular viscose rayon fibres are wetted, they have been described as losing a significant level of strength. The textile science lecturer Kathryn Hatch explains how: '[Viscose] Rayon loses about 50% of its tenacity when saturated with water.'[12]

[12] Hatch, (1993), p. 184.

Low degree of polymerisation, poor fibre orientation and high water absorptionare characteristics of viscose rayon resulting from its manufacturing process, and all contribute to its poor wet strength. The low degree of polymerisation and poor orientation of the cellulose II molecules of viscose rayon results in fewer hydrogen bonds in the fibres than are possible in the cellulose I of natural cellulosic fibres[13], hydrogen bonding being in part responsible for the high strength of cotton cellulose.[14] Viscose rayon's highly amorphous polymeric structure allows easy entry of water molecules during wetting, causing a significant amount of intermolecular hydrogen bonds to be disrupted.[15] The result is a relatively much weaker fibre when wet with clear implications for wet cleaning.

2. Test Preparation and Method

Testing aimed to investigate whether conservation wet cleaning treatments are suitable for woven viscose rayon fabrics from different time periods by highlighting any implications that the poor wet properties of viscose rayon have for such treatments.

2.1 Test Object Choice

Three test objects were chosen on the basis that: (1) fibre analysis identified them as viscose rayon; (2) the dating of each corresponded to a separate period associated with an advancement in viscose rayon processing which resulted in improved wet properties; (3) the fabric structure and density of each was as similar as possible given the *vintage* nature of the objects.

It was recognised that each test object would have been subjected to varying degrees of natural ageing. Artificial ageing was contemplated to create universal degradation levels in all specimens, however, research showed that accurately representing a specific time span and level of ageing could be difficult and this was therefore not followed.[16] It was decided that the ageing variable was inherent within the scope of this project, but that it would be considered when analysing test results.

Another inherent variable in using *vintage* objects was the lack of choice of weave type and the three test objects chosen each had different weaves: Object A plain weave, Object B twill weave and Object C crepe weave. Due to these differences, it was decided that it would not be possible to make direct strength comparisons. Instead the *tenacity* for each sample was determined. *Tenacity,* a measurement of equivalent strength between specimens of different *linear density* (mass (Kg) / Unit Length (m)), is used in the textile industry for comparing different fabric strengths.[17]

It was hoped to find white or un-dyed fabrics for testing to reduce the possibility that different colourants may have affected fibres. However, again due to limited resources this was not

[13] Gohl and Vilensky (1981), p. 58.

[14] Gohl and Vilensky, (1981), p. 45.

[15] Hearle, (2001), p. 219.

[16] Robert L. Feller, 'Chapter 4 Prediction of Useful Lifetime', in *Accelerated Aging: Photochemical and Thermal Aspects*, (USA: The Getty Institute, 1994), pp. 37-43.

[17] W. E. Morton and J. W. S. Hearle, 'Chapter 13: Tensile Properties', in *Physical Properties of Textile Fibres: Student Edition,* (Manchester: The Textile Institute, 1986), pp. 267-269.

possible. All test objects chosen contained printed colourants and obviously the effect that these may have had on fibres was considered when analysing results.

Although factors such as weave, colourants and ageing may affect results it was felt that such variables are in fact present in all objects treated by textile conservators. Textile industry testing has proven that viscose rayon suffers from weak wet strength and therefore this testing, conducted on specimens from *real* objects which have had an unknown life, sought to more accurately represent the unknown factors faced by textile conservators at work.

2.2 Test Specimen Preparation

All test specimens were prepared identically and BS 13934-1:1999[18] was used where appropriate to control specimen preparation. Specimens were cut into rectangular fabric strips with the edges cut parallel to the line of the weave. The test area of the specimens was 80mm by 25mm.[i] For each test round, ten specimens were used, five cut in the warp direction (*warp specimens)*, five in the weft direction (*weft specimens)*.

2.3 Summary of Test Variables

Given first are the variables present within the test objects, followed by the variables set for testing.

Test Object Variables:

- Date of production
- Weave structure
- Colourants (print)

Test Variables:

- Dry untreated specimens
- Wet treated specimens
  - Three wash solutions used for treatment:*
    - Non-ionic detergent
    - Anionic detergent
    - Soft water
- Dry treated specimens
  - Three wash solutions used for treatment:*
    - Non-ionic detergent
    - Anionic detergent
    - Soft water

*It was decided to test both an anionic and non-ionic detergent because no published research relating to suitable detergents for viscose rayon could be found. Soft water was used as the control solution..

2.4 Test Groups and Rounds

The different groups and rounds devised for tensile strength testing are outlined in Table 1. Individual test rounds are ordered in three main groups:
Test Group 1 dry untreated specimens,
Test Group 2 wet treated specimens and
Test Group 3 dry treated specimens.

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

Treated specimens are defined as those subjected to a controlled wet cleaning treatment.

Table 1 Test structure for tensile strength tests

Test Group	State of Specimens During Testing	Test Subgroup (Treatment)		Test Object	**Test Round**	No. Warp Specimens Tested	No. Weft Specimens Tested
1	Dry	None		A	**1-A**	5	5
				B	**1-B**	5	5
				C	**1-C**	5	5
2	Wet	Wet cleaning treatment	1 Non-ionic detergent	A	**2-1-A**	5	5
				B	**2-1-B**	5	5
				C	**2-1-C**	5	5
			2 Anionic detergent	A	**2-2-A**	5	5
				B	**2-2-B**	5	5
				C	**2-2-C**	5	5
			3 Soft water	A	**2-3-A**	5	5
				B	**2-3-B**	5	5
				C	**2-3-C**	5	5
3	Dry	Wet cleaning treatment, then air dried for 72 hours	1 Non-ionic detergent	A	**3-1-A**	5	5
				B	**3-1-B**	5	5
				C	**3-1-C**	5	5
			2 Anionic detergent	A	**3-2-A**	5	5
				B	**3-2-B**	5	5
				C	**3-2-C**	5	5
			3 Soft water	A	**3-3-A**	5	5
				B	**3-3-B**	5	5
				C	**3-3-C**	5	5

2.5 Wet Cleaning Treatment Method

To most meaningfully assess the impact for conservation of any reduction in strength as a result of wetting, all tensile tests for specimens from Test Groups 2 and 3 were preceded by a controlled wet cleaning treatment to replicate the stress and strain placed on objects during such treatments in conservation.

The controlled wet cleaning method was based on standard treatments carried out at the CTCTAH. To ensure all test specimens underwent the same extent of treatment, a standardised treatment cycle was devised, shown in Table 2.

Table 2 Wet cleaning treatment cycle

Wet Cleaning Stage	Cycle	Time (minutes)
Wash Solution added	Front: gently sponged	4
	Left	6
	Front: gently sponged	4
	Left	6
	Front: gently sponged	4
	Left	6
	Back: gently sponged	4
	Left	6
	Back: gently sponged	4
	Left	6
	Back: gently sponged	4
Soft water rinses	6 bath rinses	16
De-ionised final rinse	1 bath	10
	Total wet cleaning time:	**80**

Following wet cleaning, wet specimens from Test Group 2 were sandwiched between two layers of Melinex® to inhibit water evaporation, and, only released when ready for testing. Before testing, wet specimens were briefly placed onto blue paper towel to remove excess water and tested immediately, as suggested by British Standard (BS) 13934-1:1999.[19]

Wet treated specimens from Test Group 3 were placed onto blue paper towel and air dried for 72 hours[ii] before strength testing.

3. Tensile Strength Testing

Tensile strength testing was conducted using an Instron 5544 Tensile Strength Tester and Bluehill software version 1.4. The Instron device was set to an extension speed of 10mm per minute, with a load cell of 1000 Newtons. Test specimens were mounted with pre-tension. All testing was carried out in an uncontrolled room environment .

Analysis of results is presented in two sections; (1) comparing dry untreated specimens against wet treated specimens, (2) comparing dry untreated specimens against dry treated specimens.

[19]British Standard, (1999), p. 7.

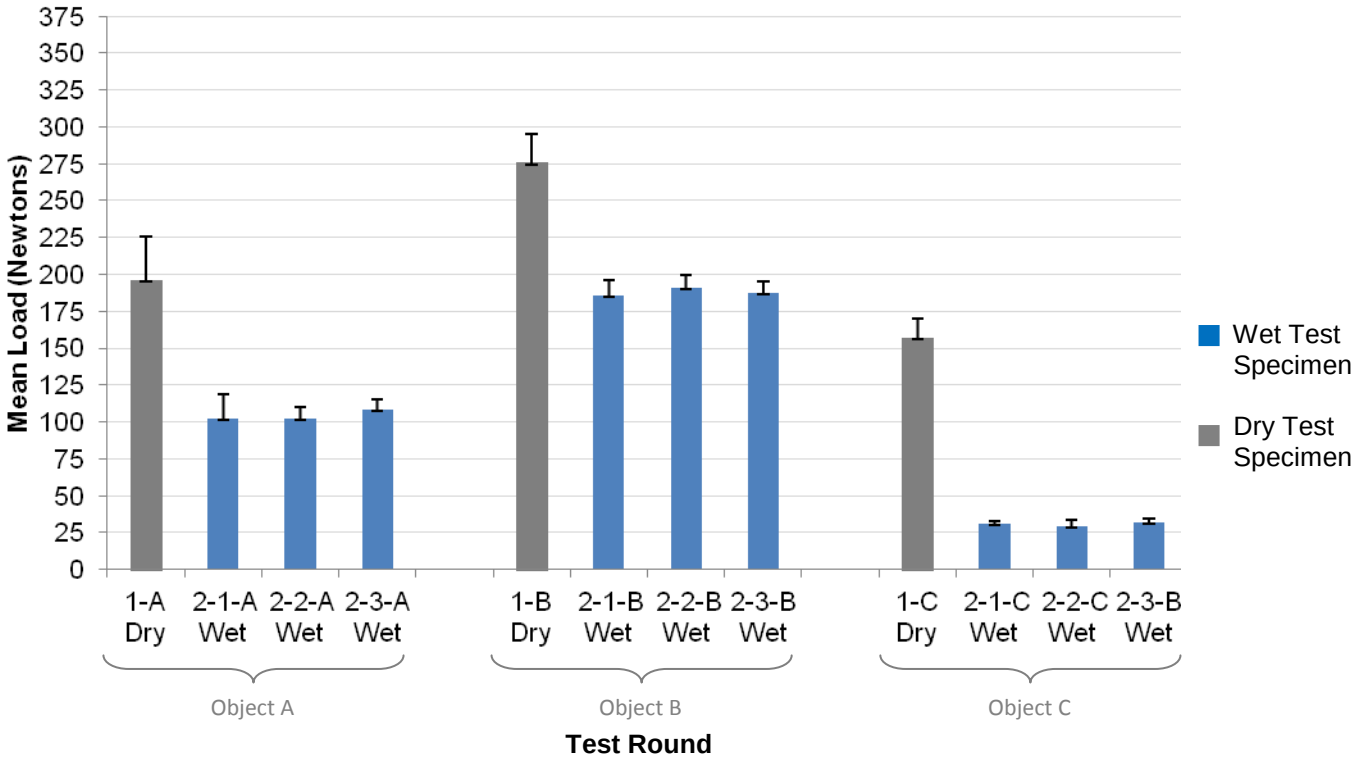
Tenacity figures given have been calculated using the following formula:[20]

$$\frac{\text{Load (N)}}{\text{(Mass in Kg / Unit length in metres)}} \times 10^{-6} = \textit{tenacity} \text{ in N/tex}$$

3.1 Comparative Analysis of Results of Test Groups 1 and 2

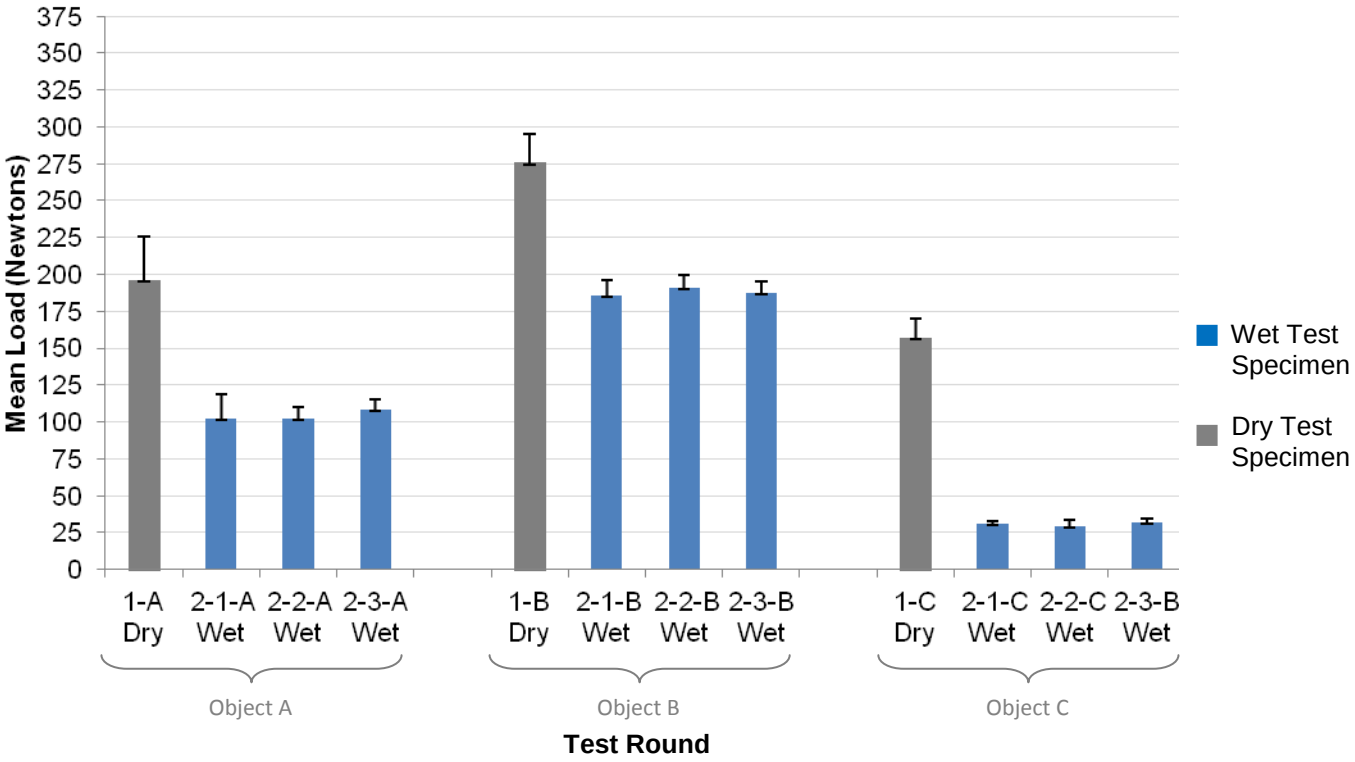
Graphs 1 and 2 compare the mean wet and dry strength of weft and warp specimens from Test Group 1 and 2. Strength here is shown as the maximum force at break applied to specimens during tensile strength tests. A significant reduction in strength in wet specimens from all objects is observed. Object C showedthe most reduced strength of all the test samples. These results however, do not take into account linear density and further interpretation in the form of tenacity calculations was therefore done.

Graph 1 - Test Group 1 versus Test Group 2 (Dry Untreated versus Wet Treated) Weft Specimens



[20] Morton and Hearle, (1986), p. 267.

Graph 2 - Test Group 1 versus Test Group 2 (Dry Untreated versus Wet Treated) Warp Specimens



Tenacity calculations, given in Tables 3-4, compare dry against wet specimen strength. These show that Object C had a significantly reduced strength when wet compared to Objects A and B. For Object C, weft specimens lost between 75.6 – 78% in strength, warp specimens between 79.3 – 81%. Objects A and B had comparable loss in strength although both were stronger than Object C. For Object A, weft specimens lost between 48.9-51.4%, warp specimens between 41.8-47%. For Object B, weft specimens lost between 40-40.7%, warp specimens between 45.7-46%.

In addition to this, there was also a marked difference in the original dry tenacity of specimens between each object in Group 1. Compared to the weft of Object A, the weft of Object C was 85.5% weaker and the weft of Object B was 52.1% weaker. And for warps, compared to Object A, Object C was 43% weaker, but Object B was 19.8% stronger. This shows that the weave structure of Object B affects weft and warp differently to that of Objects A and C. This also shows a marked difference in the dry strength of Object C, which was weaker compared with Objects A and B.

None of the three wash solutions – non-ionic detergent, anionic detergent and soft water – used for wet cleaning specimens in Test Group 2 resulted in significantly more loss of strength than another.

Statistical analysis, using the Student's t-test,[iii] to compare the significance of the differences observed for dry and wet specimens tested determined a 1:100 probability of replication of these results.

It was noted that wet specimens from Object C consistently fractured initially in areas of black print (see Illustration 2) during tensile testing but not made for dry specimens. This

suggests that the black colourant has caused degradation in these areas before further weakening by wetting the fibres . This resulted in a greater reduction in strength, as indicated by the percentage changes in tenacity described earlier. No visible weakness was seen on wet specimens from Object C in black areas before testing. It is conceivable that because Object C is dated c.1940s when wet strength was lower than later versions of viscose rayon, this degradation has had more of an impact on the fibres than it might have done in viscose rayon fibres produced later.

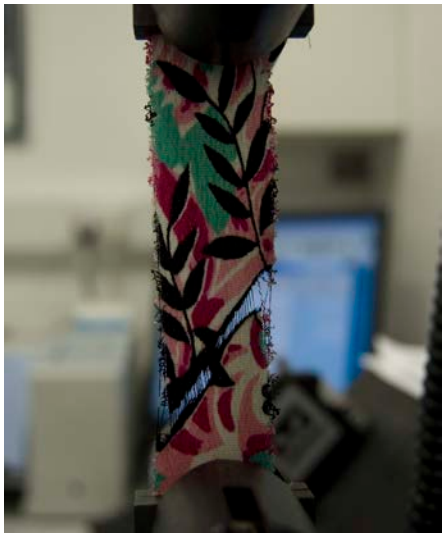
Table 3 Tensile strength from Test Group 1 and 2 (Dry Untreated and Wet Treated) Weft Specimens

Test Round	**Object A** (N/tex)	**Object B** (N/tex)	**Object C** (N/tex)
Dry tenacity – Test 1	0.0564	0.027	0.0082
Wet tenacity – Test 2-1	0.0288	0.016	0.0018
Wet tenacity – Test 2-2	0.0282	0.016	0.002
Wet tenacity – Test 2-3	0.0274	0.016	0.002
Percentage drop in strength	**51.4 – 48.9%**	**40.7 – 40%**	**78 – 75.6%**

Table 4 Tensile strength from Test Group 1 and 2 (Dry Untreated and Wet Treated) Warp Specimens

Test Round	**Object A**	**Object B**	**Object C**
Dry tenacity – Test 1 (N/tex)	0.0526	0.063	0.03
Wet tenacity – Test 2-1 (N/tex)	0.028	0.0338	0.0062
Wet tenacity – Test 2-2 (N/tex)	0.0278	0.0342	0.0056
Wet tenacity – Test 2-3 (N/tex)	0.0306	0.0336	0.0062
Percentage drop in strength	41.8 – 47.1%	45.7 – 46.7%	79.3 – 81.3%

Figure 2 Fracturing in areas of black dye on a specimens from Object C, Test 2-1-C

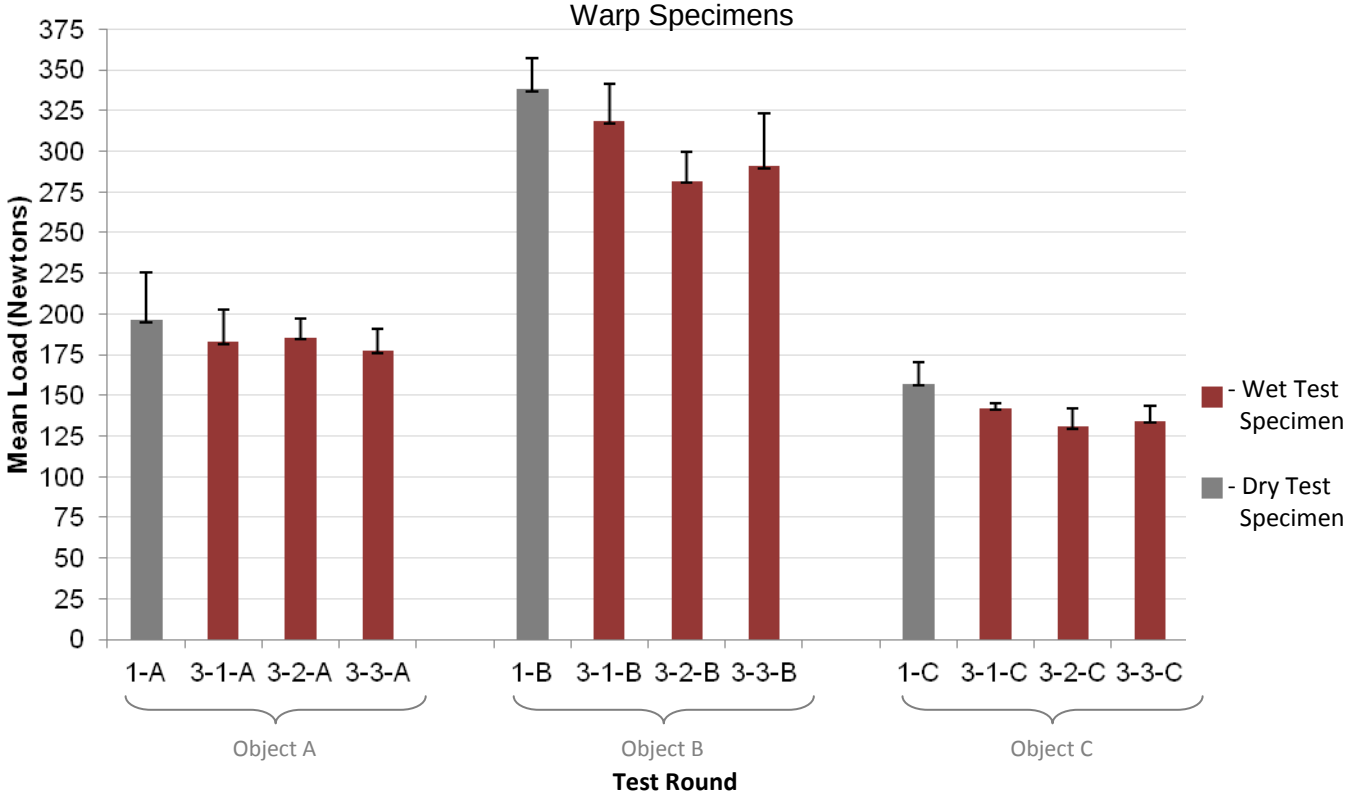


3.2 Comparative Analysis of Results of Test Groups 1 and 3

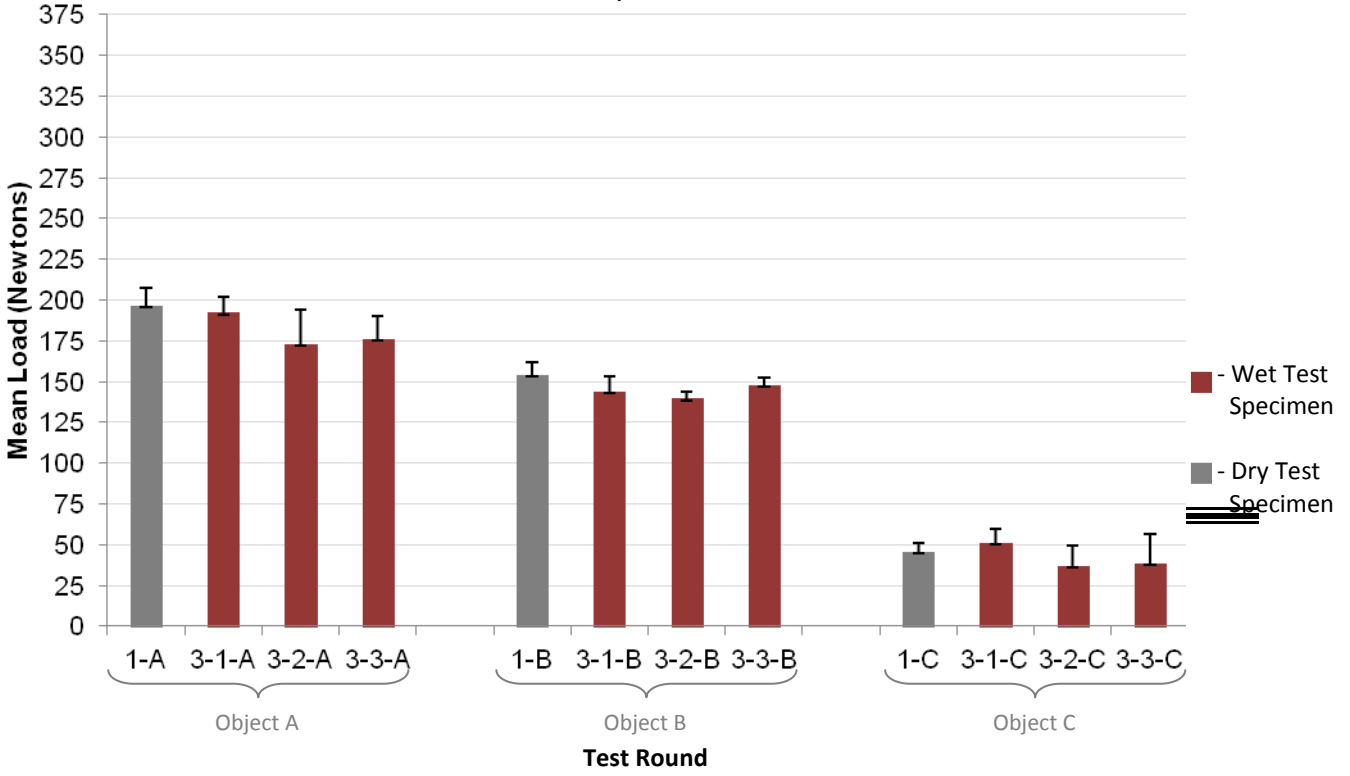
Graphs 3 and 4 compare the mean dry strengths for untreated and wet treated weft and warp specimens of Test Group 1 and 3. These appear to show that a significant amount of

the strength lost from wetting was returned upon drying, although it appears there was some slight reduction in strength incurred in all specimens in Test Group 3 after wet cleaning treatment. Again, tenacity calculations were analysed to take into account any differences in linear density between test specimens of the same object.

Graph 3 Test Group 1 versus Test Group 3 (Dry Untreated versus Dry Untreated)
Warp Specimens



Graph 4 Test Group 1 versus Test Group 3 (Dry Untreated versus Dry Untreated)
Weft Specimens



Tenacity calculations shown in Tables 5 and 6 provide a truer equivalent strength for comparisons between Test Group 1 and 3. These show that there were a range of differences in mean strength between Test Group 1 and 3 for all three test objects. At first these results appear significant, with ranges of a loss in tenacity of 4.6% in weft specimens from Test 3-1-A to 23.8% in warp specimens from Test 3-3-B and a gain in tenacity of +0.8% in warp specimens from Test 3-2-A and +24.4% in warp specimens from Test 3-1-C.However, statistical analysis in the form of the Student's t-test revealed that the strength changes between Test Group 1 and 3 for the majority of test rounds were in fact insignificant and had a low chance of replication in future tests of 1:1000. The exceptions were in the following test rounds, shown next to their percentage change in dimensions and ratio probability of replication:

- Weft specimens 3-1-B, $^{-}$4.4% - 1:20 ratio
- Weft specimens 3-2-B, $^{-}$4.4% - 1:20 ratio
- Warp specimens 3-2-C, $^{-}$14% - 1:20 ratio
- Warp specimens 3-2-B, $^{-}$20.9% - 1:100 ratio

Statistical analysis suggests that wet cleaning with detergent wash solutions has had some effect on permanent strength for Objects B and C, but no effect on Object A. The soft water control wash solution had no significant effect on strength. The majority of specimens which suffered significant loss in strength had been wet cleaned with a Orvus WA® (anionic) detergent solution. As results were not unanimous throughout specimens treated with Orvus however, it is not possible to suggest that this detergent is likely to have a definitive permanent effect on strength in viscose rayon. In addition, other factors, such as unknown stress and strain put on test fabrics during their lifetime could have affected results.

Dry specimens from Object C did not just fracture first in areas of black colourant as had been observed for Test Group 2, suggesting the likelihood that any reduction in strength in these areas was reversed upon air drying.

Table 5 Tensile strength from Test Group 1 and 3 (Dry Untreated and Dry Treated) Weft Specimens

Test Round	**Object A**	**Object B**	**Object C**
Dry tenacity – Test 1 (N/tex)	0.0564	0.027	0.0082
Dry tenacity – Test 3-1 (N/tex)	0.0538	0.0258	0.0102
Dry tenacity – Test 3-2 (N/tex)	0.0484	0.0252	0.0072
Dry tenacity – Test 3-3 (N/tex)	0.0512	0.0278	0.0078
Percentage drop in strength	$^{-}$4.6 - $^{-}$14.2%	$^{+}$3 - $^{-}$6.7%	$^{+}$24.4 - $^{-}$14%

Table 6 Tensile strength from Test Group 1 and 3 (Dry Untreated and Dry Treated) Warp Specimens

Test Round	**Object A**	**Object B**	**Object C**
Dry tenacity – Test 1 (N/tex)	0.0526	0.063	0.03
Dry tenacity – Test 3-1 (N/tex)	0.0502	0.0582	0.0284
Dry tenacity – Test 3-2 (N/tex)	0.053	0.0498	0.0258
Dry tenacity – Test 3-3 (N/tex)	0.048	0.048	0.0276
Percentage drop in strength	$^{+}$0.8 - $^{-}$8.75%	$^{-}$7.6 - $^{-}$23.8%	$^{-}$5.3 - $^{-}$14%

3.3 Tensile Strength Test Results Summary

Testing conducted concluded that both older and more recent examples of viscose rayon all display poor wet properties. This confirmed …

During tensile strength testing, wet specimens put up little resistance to an increased load and tended to fracture quickly, causing the specimens to split in two. Following a controlled wet cleaning treatment, specimens from Object A (c.1980-90s) and Object B (c. 1960s) both suffered a reduction in tenacity of around 50%. Tensile strength test results for Object C (c.1940s) showed it was most affected by the controlled wet cleaning treatment, with a decrease in tenacity of up to 81%. However, it appears that wet tensile strength testing for Object C was affected by the black colourant present in the printing on the fabric. Statistical analysis showed that these results were significant.

Neither Orvus WA® (anionic) nor Dehypon LS45® (non-ionic) detergents appeared to significantly affect wet strength more than the other and therefore it is concluded that both are suitable for use for wet cleaning viscose rayon fibres.

Mixed results were obtained from tensile strength tests designed to show whether reductions in strength caused by the controlled wet cleaning treatment were reversed upon air drying. However, statistical analysis comparing each showed that most of these changes were insignificant. Of those shown as significant, these did not unanimously show that either detergent tested had a significant effect on permanent strength.

It should be noted that although comparison of results using tenacity took into account the linear density of specimens from the three test objects, the weave type may have affected results to some extent, with some weave constructions producing stronger fabrics than others. In addition, it was not known whether any finishes were applied to the fibres during manufacture and this may have had some impact on results. However, as results for both Object A and B were similar, this may indicate that these factors had little effect on specimens from either object. In terms of the different levels of ageing of the different fabrics, it is clear that degradation over time has had some impact on specimens form Test Object C. The similar results obtained for Objects A and B however, suggest that differential levels of ageing may not have significantly impacted on tensile strength test results.

4. Conclusions and Recommendations for Conservation

Research into the history and manufacture of viscose rayon highlighted the plethora of manufacturing processing finishes used and how these may affect fibres differently. In particular, viscose rayon can be produced to appear like silk, cotton or wool. Conservators should be aware of the diversity of appearances and properties possible for this fibre.

Research showed that early viscose rayon, pre-1940s, may have even poorer wet strength than the dated examples tested for this project. However, this could not be investigated, as an example of viscose rayon from this early period was not found.

Test results for wet specimens from Object C, c.1940s, showed a reduction in tenacity of around 80%. However, it is likely that degradation inflicted by the black colourant in specimens affected results to some extent. The impact that the degradation had on c.1940s specimens may indicate that the reduction in strength that occurs when viscose rayon fibres are wetted greatly exacerbates weaknesses from degradation. It is possible that the way the c.1940s specimens behaved during testing could highlight an issue with viscose rayon textiles in general. Areas which may appear strong prior to wet cleaning but which have undergone a certain level of degradation may become weakened enough through wetting for

splitting to occur in those areas. This may be difficult for conservators to predict and may possibly be an issue in the future as viscose rayon textiles become older and more degraded, though more research is required into this.

It is evident that the loss in strength incurred on viscose rayon during wet cleaning resulted in causing stress on fibres of whatever age. Whereas tests on specimens dried following wet cleaning indicated that most did not suffer significant permanent strength loss, more research is required to verify how representative these results are because a few specimens did show more significant strength loss.

It is concluded that wet cleaning can be a suitable treatment option for viscose rayon from different times providing objects are acutely monitored during treatment for any signs of weakening from wetting which could cause splitting. Tensile strength tests conducted on wet specimens resulted in quick fracturing, causing whole specimens to be split in two. It is possible that this behaviour may be replicated in any viscose rayon fibres which become sufficiently weakened to fracture in the wash bath. The number of wet cleaning treatments viscose rayon objects are subjected to should be minimised, to reduce the number of times wetting puts stress on fibres. If fibres are visibly degraded in any way, wet cleaning may not be appropriate as fibres are likely to be weakened by at least around 50%, significantly increasing the risk of further damage to fibres during such treatment. Tímár-Balázsy and Eastop, mention using a framed net support when cleaning viscose rayon and this seems like good advice, to reduce strain put on fibres.[21]

Acknowledgements
The authors are grateful to Professor Liz Tanner, Department of Mechanical Engineering, University of Glasgow, and Dr Margaret Smith, Icon conservation science intern, CTCTAH, for their invaluable assistance with devising the tensile tests and resulting data interpretation.

[i] It was aimed to have a test area of 100/25 mm, half the recommended size in BS 13934-1:1999. However, allowing excess fabric for clamping specimens in the Instron device was overlooked and, due to a limited supply of test fabric, the test area had to be reduced.

[ii] The time of 72 hours was partly arbitrary as testing was started on a Friday and access to the *CTCATH* was not available over the weekend.

[iii] The *Student's t-test* calculates the significance of results and shows the probability that future tests would replicate the same contrast between the dry and wet strength.

[21] Tímár-Balázsy and Eastop, (1998), p. 142.