Kanika Sachdeva, et. al. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 10, Issue 9, (Series-I) September 2020, pp. 49-61

RESEARCH ARTICLE OPEN ACCESS

Effect of Fabric Construction on the Longevity of Aged Cotton Fabric

KANIKA SACHDEVA*, MONA SURI**, SIMMI BHAGAT***
(Researcher & Entrepreneur)
(Academic Vice President, Royal University for Women, Bahrain)
(Associate Professor, Department of Textiles & Clothing, Lady Irwin College, University of Delhi)

ABSTRACT

It is widely known that construction parameters like thread count and weave type have profound impact on performance of the fabrics during their useful lifetime. This paper takes the same approach to conservation science where impact of thread counts and weave type has been experimentally explored in context of cotton fabric longevity. While certain weave types have traditionally been associated with strength and toughness, change in their performance over the period of time has only been documented empirically. However, novel technologies require hard core data to develop precision instruments. Current paper provides data driven comparative assessment of impact of thread count and weave type on strength and performance of cotton fabrics over the period of time. Change in strength and performance properties of cotton fabrics of varying thread count and weave over the period of stipulated time has been established utilising standardized accelerated ageing mechanisms. Results obtained by these experiments reveal important information about varied impact of ageing on fibres made of same yarn but different constructional parameters. Findings of this research where on one hand experimentally establish the impact of constructional parameters on life and longevity of textile artefacts, it also provides valuable deterioration data that can find multiple applications in development of advanced instrumentation aided by data driven technologies.

KEYWORDS: Abrasion resistance, Accelerated Ageing,Cotton, Deterioration data,Extra Warp, Flexural rigidity,Museum textiles,Plain weave, Satin Weave, Twill Weave, Thread count GSM, Tensile testing, Whiteness Index, Yellowness Index

Date of Submission: 20-08-2020 Date of Acceptance: 06-09-2020

I. INTRODUCTION

There are multiple factors that impact the longevity of any object in the museum environment. Apart from external agents of degeneration like light and humidity, the inherent characteristics of textiles play a major role in deciding the life span of a textile artefact. This paper presents a section of a larger doctoral study where museum textiles, their longevity and deterioration has been tested and recorded to obtain deterioration data in context of fibers, thread count, weave type and finishing parameters mapped with various strength and performance parameters. In the present paper, construction parameters like thread count and weave type have been studied to understand their role in retarding or promoting the degeneration process in textiles.Impact of intrinsic textile characteristics on longevity of fabrics has been pointed out by some other researchers as well. Studies have shown that different fabric weaves differentiate the structure of fabrics, and these different structural properties of fabrics will cause the fabrics to behave differently from each other. However, none of these studies have been conducted in the context of museum fabrics or aged fabrics. Kaynak and Topalbekiroglureported that long yarn floats and a low number of interlacing decrease the abrasion resistance of woven fabrics by increasing the mass loss [1]. Similarly, a study by Cardamone concluded that chemical and morphological differences dictate how applied chemical, physical and mechanical forces will affect a historic textile [2]. Pan also reported that theyarn cross-section and surface property, the yarn strength, fibre volume fractions of the fabric and theyarns, and the external loads exerted on the fabric aredemonstrated to be the important variables determiningthe fabric tensile strength [3].

In order to understand and manage deterioration, it is important that all these aspects are studied individually. Thus, each factor needs to be singled out in an environment where all other parameters have been kept constant. This ensures that only one variable is playing at a time, providing better understanding of its role in the complete story of ageing.In order to understand the useful lifetime of a product, it is imperative to understand its process of ageing. Accelerated ageing is the best suited tool which curators, conservators and scientists, world over use to study and understand the reaction of a product to various circumstances it is expected to encounter in its lifetime[4].

Thisresearch intended to discover the relationship between fabric characteristics and longevity of a textile. Fabric samples of different construction were exposed to accelerated ageing mechanisms. Keeping all the external factors constant, construction of the fabric was varied step-by-step, in order to understand ageing mechanism. Changes in parameters like tensile strength etc. were studied as indicators of effect of ageing on the fabric.

II. MATERIALS AND METHODS

2.1. Sample Selection and Simulation: Although plain weave is known to be the precursor to all other types of weaves, twill and satin have been other important variations in history of textiles. Exclusively or in combination, these three weaves are responsible for creation of most woven artefacts. Extra warp or weft yarn though doesn’t change the nature of interlacement of yarns in a fabric; it designates additional strength to a particular direction of the same. Thus, this simple variation is capable of generating huge disparity in strength dynamics of the fabric in question. Since most other weaves are combinations or adaptations of these three weave types, it was decided to study each one of them in isolation. Additionally, in plain weave, closeness of yarns in the fabric effect strength, thickness and pliability of the fabric in question. Thus, three thread count variations, high, medium and low, were selected for the purpose of investigation.

*2.1.1. Constants***:** For the purposes of fabric simulation constants for research were

1. Fiber: Cotton was selected as constant for further research. It was realized that museums house sizeable collections in cotton. Furthermore, cotton still retains its position as the most pervasive one in this age of man-made fibers and thus museums globally expect to increase their collections in cotton at a rate higher than that of any other fibers.
2. Yarn count: It is a well-known fact that exclusive textiles in earlier centuries were made in finer yarn counts. Thus, museums today hold reasonable amounts of both high and low yarn counts. Looking at these findings and availability, **60s** was selected as reference yarn count and all fabric required for research were customized with this specification. Care was taken to use only single/non-plied yarn for fabric construction, so that possibility of secondary factors impacting experimental results could be ruled out.

Fabric for experimentation was developed with these two factors as constants and customized taking into consideration the variables decided for each section of experimentation. The yarn for the purpose was sourced from expert yarn sizers of *Salem* district in Tamil Nadu (India). The coordination was done by the specialized wing of Ministry of Textiles (India) - Weaver Service Centre, Bangalore, as they developed the procured yarn into desirable fabric variations on their in-house looms. Two handlooms of Weaver Service Centre Bangalore were deployed exclusively for developing samples for this research.

*2.1.2. Variables:*All basic construction parameters that can bring variation to a textile were examined. A systematic individual approach to all these parameters was developed, so that a meaningful conclusion could be arrived at.Fabric construction parameters were varied based on weave type and thread count. The fabric variations were developed as in Table 1.

Table 1: Details of Variables in the study

Weave	**Thread Count**		
	Low	Medium	High
Plain weave	**45X40**	**80X70**	**106X85**
Plain Weave with extra warp	**-**	**72X72**	**-**
Twill weave	**-**	**84X81**	**-**
Satin weave	**-**	**82X76**	**-**

2.2. Indicators: Samples were tested for parameters mentioned as indicators and their values recorded. For the purpose of quantitative evaluation, certain strength and performance properties were selected to indicate level of deterioration after accelerated ageing. Further, Standard Deviation (SD) and Coefficient of Variation (CV%) values were calculated for readings obtained so that accuracy of the experiments could be established. The customized fabric samples were tested and compared for following parameters:

1) Fabric Weight: Five samples of each fabric type were weighed for the purpose to get average value. Standard Deviation (SD) values and Coefficient of Variation (CV%) was also derived for the purpose of statistical analysis. Change in GSM of fabrics indicated the extent and direction of alteration in fabric character.

2) Tensile Strength: Grab Test- ASTM D 5034-09 was used. Values for the breaking force and theelongation of the test specimen were obtained.From each testing sample, five specimens from the warp direction and eight specimens from the filling direction were taken as per the procedure specified in the standardised test.Also, SD and CV% was duly calculated for statistical analysis.

3) Abrasion Resistance: ASTM D4966-98(2004) test method covers the abrasion resistance of textile fabrics using the Martindale abrasion tester. The mass loss (as the difference between the Initial mass and Final mass after abrasion) was evaluated. The mass loss difference before and after abrasion was reported as weight loss in milligrams or as a percentage calculated by the formula:$((A-B)/A)*100$ where A = Initial weight, and B = Final weight.

For the purpose of eliminating error, four samples were tested from each fabric type and their average reading considered for final comparison. Additionally, SD and CV% was calculated for statistical analysis.

4) Flexural Rigidity: ASTM D-1388-08 (Cantilever Test) test method covers the measurement of stiffness properties of fabrics. The bending length for each testing direction was measured to the nearest 1 mm, using$c = O/2$where c = bending length, mm, and O = length of overhang, mm.

The flexural rigidity for each testing direction to three significant digits was calculated using

$G = 1.421 * 10^{-5} * W * c^3$ where:

G = flexural rigidity, μjoule/m, W = fabric mass per unit area, g/cm2, and c = bending length, mm.

Procedure: Alternate Oven Test: Specimens were steam-aged in a moist atmosphere under controlled conditions and then tested for loss in strength due to storage degeneration. The equipment used for the process of ageing was a Hot Air Oven. The oven was equipped with a fan to circulate hot air for uniform heating throughout the chamber. Also, the equipment had vents located on both sides as per the specifications of AATCC standard. The specimens were exposed to 135+/-2C (275+/4F). Samples were tested for strength and performance properties before the treatment. Thereafter, samples were continuously heated in the oven for six hours. As per the standard, for each fabric variation, four samples each, warp and weft direction were analyzed and readings from each sample were taken from four sides. Thus, an average of the 16 readings for each direction was taken as final value for result and comparison. The analysis was supplemented by calculating their SD and CV%.

5) Change in Color: ASTM E-313-00 test methodprovides numbers that correlate with visual ratings of yellowness or whiteness of white and near white or colourless object-colour specimens, viewed in daylight by an observer with normal colour vision.

Yellowness Index: $YI = 100(C_X X - C_Z Z)/Y$

Whiteness Index**:** $WI = Y + (WI, x)(x_n - x) + (WI, y)(y_n - y)$

where: Y, x, y = the luminance factor and the chromaticity coordinates of the specimen, $x_n$and y_n= the chromaticity coordinates for the CIE standard illuminant and source used, and WI, x and WI, y = numerical coefficients.Formula: Hunter, Observer: 10^0, Source: U35(http://www.hunterlab.com/manuals/cfchapter10_2_4.pdf)

2.3. Accelerated Ageing To comprehend the precise phenomenon of ageing, selected fabrics were subjected to an artificial ageing process. Oven test of AATCC-26 was selected for artificial ageing of the fabrics selected for research (AATCC Technical Manual, 1995). This test method describes a procedure for determining deterioration of textile materials under normal storage conditions and establishes the degree of such deterioration. It has been noted by conservation scientists that maximum degradation in heat ageing happens in the first 6 hours of heating which alternatively has also been equated with first 20 years of life of a textile.[4],[5] A timespan of 6hrs of heating was finalized in consultation with the test method laid out and Feller's assertion which equated this to approximately 20 years of useful lifetime of a product [6]

The placement of samples in the oven was such that no part of the sample touched metallic body of the oven. To achieve this, samples were hung on the wire racks with the help of cotton threads. Care was taken that no part of the fabric was held in tight folds, so that whole fabric could be aged uniformly. At the beginning of the test, 100ml of water for each 0.03cu m (1.0 cu ft) of oven capacity was introduced into the oven to facilitate controlled steam ageing. The vents were left open during the entire test. At the end of the six hours of heating, the specimens were removed from the oven.

III. RESULTS AND DISCUSSIONS

Comparative analysis of test values obtained for the four weave variations and three thread count variations helped in determining the role of yarn interlacement in fabric deterioration. The analysis of the obtained data provided a clear picture about the kind of weave that gives in most easily to deterioration and the one which stands against it. Impact of thread count on the process of degeneration was also experimentally established with numerical data. Individual effect of all these parameters could be concluded after the above-mentioned procedure and particular construction or finishing parameter that encouraged or discouraged the course of deterioration could be identified.

3.1. Comparison of Change in Thread Count Variations

Comparison of three thread counts on the basis of selected strength and performance characteristicsprovided a clear understanding of how variation in thread count impacts the properties of fabrics post ageing. This analysis is also important for situations where made-ups comprise of more than one type of fabric coming from the same fiber. Thus, results obtained would assist conservators in predicting the behavior of aged and un-aged fabrics with thread-count variations and deciding upon suitable treatments for the same.

3.1.1 GSM

As evident from the Table 2, all three-thread count variation display insignificant increase in GSM after ageing. This marginal increase in GSM could be due to shrinkage of yarns under impact of heat and moisture. Also, the results of GSM mapping clearly indicate that there is no difference in loss of matter because of thread count variation in plain weave fabrics after ageing unless an additional action is taken.

Table 2: Comparative effect of Ageing and Thread Count on GSM of Cotton Fabric

Thread count	**45X40**		**80X70**		**106X85**	
	Before Ageing	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**
Average	**39**	**40**	**63**	**63**	**80**	**81**
Standard Deviation	**1.0955**	**0.83666**	**1.673320**	**0.836660**	**1.923538**	**1.816590**
CV %	**2.8233**	**2.10216**	**2.673035**	**1.323829**	**2.410449**	**2.231683**
T-Test	**0.044505**		**0.250585**		**0.097569**	
% change in GSM	**-2.58**		**-0.96**		**-2.01**	

3.1.2 *Tensile Strength:*

This was analyzed in terms of Breaking Load and Extension before break.

Breaking Load-Warp Direction: It can be seen from Table 3 that breaking load in the warp direction increases with increase in thread count. The trend noted is that low thread count fabric suffers maximum reduction in strength and highest thread count fabric suffers lowest reduction in strength post ageing. This can be attributed to increased strength because of increased number of yarns to share the load and also higher per capita exposure of heat to fibers in low thread count fabric.

Breaking Load-Weft Direction: Pre-ageing trends in breaking strength are similar to that in the warp direction. However, post ageing, the trend reverses in weft direction. This indicates that warp sizing has some role to play in changing strength of yarns post-ageing.

Extension %-Warp Direction: Again, it can be seen that extension before break increases with increase in thread count, both pre and post ageing. This revelation places higher thread counts fabrics at a distinct advantage to their low thread count counterparts.

Extension %-Weft Direction: Depicted trend for extension in weft direction differs slightly from the warp direction. Although low thread count illustrates lower extension, medium thread count fabric depicts slightly higher extension than the high thread-count counterpart. This can be attributed to restriction in movement of yarns in case of a high thread count fabric.

Table 3: Comparative effect of Ageing and Thread Count on Breaking Load and Extension of Cotton Fabric

	Thread count	45X40		80X70		106X85	
		Before Ageing	After Ageing	Before Ageing	After Ageing	Before Ageing	After Ageing
BREAKING LOAD (Warp) (N/m^2)	Average	4.82	1.32	7.96	5.48	9.30	5.96
	Standard Deviation	0.676018	0.130384	0.673053	0.601664	1.104536	0.391152
	CV %	14.025265	9.877579	8.455437	10.979277	11.876732	6.562955
	T-Test	0.000089		0.004566		0.003372	
	% Change	72.61		31.16		35.91	
BREAKING LOAD (Weft) (N/m^2)	Average	3.95	3.30	7.29	4.95	8.41	5.79
	Standard Deviation	0.68	0.46	1.02	0.50	1.11	0.71
	CV %	17.17	13.84	14.00	10.07	13.23	12.34
	T-Test	0.031776		0.000350		0.000282	
	% Change	16.46		32.08		31.20	
EXTENSION % (Warp)	Average	6.67	3.33	13.00	5.33	17.00	8.33
	Standard Deviation	1.18	0.00	1.83	0.75	1.40	0.00
	CV %	17.68	0.00	14.04	13.98	8.20	0.00
	T-Test	0.001599		0.000163		0.000078	
	% Change	3.33		7.67		8.67	
EXTENSION % (Weft)	Average	10.42	6.67	20.21	8.33	16.88	7.08
	Standard Deviation	1.18	0.00	3.01	0.00	1.39	0.77
	CV %	11.31	0.00	14.91	0.00	8.24	10.89
	T-Test	0.000021		0.000005		0.000000	
	% Change	3.75		11.88		9.79	

Comparison of change in Tensile Strength and Extension within various Thread Counts:

The summary of comparison (Table 3) indicates similar behavior of medium and low thread count weaves in response to ageing. Both thread-count variations lose approximately 1/3rd of their tensile strength after ageing. However loose weave fabric does not confirm to the trend followed by other two. Extremely high strength reduction in warp direction and very lowreduction in strength in weft direction indicate that apart from thread-count, starch plays an important role in degeneration of fabric due to ageing. Warp sizing combined with higher exposure to heat is a possible reason for higher strength loss in warp direction of low thread-count fabrics. Also, it has been observed that extension of yarns before breakage and reduction in this property are lower in fabrics with low thread-count. Whereas, medium and high thread-count fabrics demonstrate higher loss in extensibility.

Thus, it can be concluded that cleaning and display procedures for low thread count fabrics need to be handled more delicately than fabrics with medium or high thread count. Medium and high thread-count fabrics can be predicted to retain 2/3rd of strength even after 20yrs of ageing. However, extensibility of medium and high thread count fabrics suffers considerably after ageing, therefore hanging displays should either be completely avoided or designed with enough lateral support.

3.1.3 *Abrasion Resistance:*

Abrasion resistance readings mapped in Table 4 needs to be analyzed with a different perspective. It took different number of cycles to attain approximately 20% reduction in weight of the samples for three set of fabrics. Where loose weave fabric attained this weight loss in 3800 cycles, medium and high weave fabrics were inconclusive at this stage. It took 5500 cycles for the medium weave fabric and further 8500 cycles for high weave fabric to attain this level of weight loss. This reinforces the fact that close woven fabrics are better equipped to counteract damage caused due to abrasion. Also, these fabrics demonstrate negligible change in trend post-ageing, indicating that this level of ageing does not impart much change to the surface properties of the fabric.

This observation can have interesting implications in cleaning, display and storage procedures of museum textiles. It can be safely concluded that cleaning procedures like sponging need to be less vigorous for low thread count weaves as compared to weaves with higher thread count.

Table 4: Combined Effect of Ageing and Thread count on Abrasion Resistance of Cotton Fabrics

		WEIGHT OF FABRIC (gms)					
		Before Ageing			**After Ageing**		
Thread Count	**Sample No.**	**Initial weight**	**Final weight**	**% change in weight**	**Initial weight**	**Final weight**	**% change in weight**
45X40 (3800 cycles of abrasion)	Average	**0.05**	**0.04**	**22.50**	**0.05**	**0.04**	**21.25**
	Standard Deviation	**0.01**	**0.01**		**0.01**	**0.01**	
	CV %	**12.83**	**16.50**		**10.53**	**13.33**	
	T-Test	**0.318809**					
	Change in weight loss	**-1.25**					
80X70 (5500 cycles of abrasion)	Average	**0.095**	**0.073**	**23.61**	**0.093**	**0.063**	**32.50**
	Standard Deviation	**0.01**	**0.01**		**0.01**	**0.01**	
	CV %	**6.08**	**6.90**		**5.41**	**8.00**	
	T-Test	**0.008850**					
	Change in weight loss	**8.89**					
106X85 (8500 cycles of abrasion)	Average	**0.10**	**0.08**	**21.82**	**0.10**	**0.08**	**20.00**
	Standard Deviation	**0.01**	**0.00**		**0.01**	**0.01**	
	CV %	**4.88**	**0.00**		**5.13**	**6.45**	
	T-Test	**0.585104**					
	Change in weight loss	**-1.82**					

3.1.4 Flexural Rigidity:

The detailed table of readings for Bending Length and Flexural Rigidity can be obtained from authors on request. Bending Length trends before ageing clearly indicate the role of thread-count in fabric stiffness. Clear ascent in bending length can be seen with increase in number of yarns in the fabric. Also, the bending length is lower in weft direction as compared to warp, indicating the role of warp sizing for the same (Table 5). Post-ageing trends reveal near to 50% decrease in Bending Length and approximately 85-90% increase in rigidity of the fabrics. Also, the loss in rigidity increases marginally with increase in thread-count.

Table 5: Effect of Ageing and Thread Count on Bending Length and Flexural Rigidity of Cotton Fabrics

	Sample No.	**BENDING LENGTH** (mm)			**FLEXURAL RIGIDITY** (μjoule/m)		
		Before Ageing	After Ageing	% Change	Before Ageing	After Ageing	% Change
45 X40	Warp Average	**2.26**	**1.21**	**46.40**	**0.00000068**	**0.000000105**	**84.49**
	Weft Average	**1.16**	**0.66**	**43.55**	**0.00000009**	**0.000000017**	**81.28**
80X 70	Warp Average	**2.68**	**1.50**	**44.15**	**0.00000175**	**0.000000323**	**81.54**
	Weft Average	**1.59**	**0.78**	**50.79**	**0.00000036**	**0.000000049**	**86.30**
106 X 85	Warp Average	**2.81**	**1.40**	**50.22**	**0.00000264**	**0.000000339**	**87.16**
	Weft Average	**2.17**	**0.84**	**61.38**	**0.00000118**	**0.000000070**	**94.11**

Thus, it can be inferred that 20yrs of ageing bring about substantial loss in rigidity of the fabric, thus the drape and fall of fabrics can be expected to change drastically after this time-span. Also, the trend of loss in rigidity is expected to intensify in fabrics of high thread-count.

3.1.5 Change in Colour:

The trend (Table 6) clearly indicates increase in yellowness of fabrics after ageing. Increase in Yellowness index is almost similar in the three thread count variations.

Table 6: Effect of Ageing and Thread Count on Color properties of Cotton Fabrics

		R	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**
45X40	Before Ageing	194.00	193.00	162.00	53.58	50.15	18.95	70.81	1.23	9.28	(-) 180.44	(-) 60.09	95.58
	After Ageing	193.00	190.00	151.00	53.69	49.65	16.88	70.46	2.79	11.60	(-) 195.98	(-) 66.22	101.63
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							2.83	(-) 0.35	1.56	2.33	15.53	6.13	(-) 6.04
80 X70		**R**	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**
	Before Ageing	200.00	197.00	164.00	58.67	54.46	20.10	73.79	2.40	10.25	(-) 179.0	(-) 63.36	97.75
	After Ageing	201.00	196.00	154.00	59.84	55.01	18.27	74.17	3.75	12.74	(-) 193.37	(-) 68.69	103.37
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							2.86	0.37	1.35	2.49	14.37	5.33	-5.61
106 X85		**R**	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**
	Before Ageing	211.00	208.00	171.00	66.78	62.04	23.05	78.77	2.43	10.76	(-) 170.46	(-) 62.95	97.35
	After Ageing	199.00	194.00	151.00	58.15	53.39	17.44	73.07	3.85	12.91	(-) 197.24	(-) 69.43	104.17
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							6.25	-5.69	1.42	2.15	26.79	6.48	-6.82

Summarizing the results obtained after the above-mentioned experiments, provided a better insight about role of thread-count and weave variation on performance and strength characteristics of a textile. Data obtained has established that increase in yarn density in a fabric is directly proportional to increase in their strength. Another interesting trend to be noted is that the impact of ageing is seen in enhanced manner in loose weave fabrics, warp direction. Alternatively, weft direction yarns display quite low strength as compared to their higher thread-count counterparts, but percentage decrease in strength is lower. Thus, close woven fabrics can be expected to show better resistance to tear in stress causing situations and loose weave fabrics often lower in strength both pre and post ageing. Also, resistance to strain is found to be higher in close weave fabrics and loss to this property is higher for the same. Similarly, fabrics have displayed increased resistance to abrasion with increase in number of yarns in their weave. Additionally, data obtained has correlated increasing number of yarns with increased stiffness in unaged fabrics and higher loss of rigidity after ageing. Thus, high thread-count fabrics suffer slightly more in terms of losing original drape and fall after ageing. However, the three thread-counts show similar weight change and color change due to ageing. Also, Standard Deviation and CV% values indicated minimal experimental error. Thus, it can be concluded that close weaves are expected to pose comparatively lesser challenges to care-takers when it comes to procedures involving stress-and strain situations, like hanging displays and abrasion during cleaning and display procedures. However, ageing is expected to pose greater damage to original drape and fall of fabrics with close weaves as compared to open weave fabrics.

3.2 Comparing Change in Weave Variations

Predicting behavior of different weaves is an important issue faced by conservators as differences in thread alignment leads to variations in performance characteristics of fabrics. Mapping the behavior of different weaves would provide useful insight about impact of yarn interlacement on fabric performance. The weaves considered for testing are plain, twill, satin and extra warp variation of plain weave.

3.2.1 *GSM:*

The pre-ageing GSM readings obtained are indicative of amount of fiber mass utilized per unit of respective weave.

Table 7: Effect of Ageing and Variations of Weave on GSM in Cotton Fabrics

	GSM (gms)							
Sample No.	**Plain**		**Twill**		**Satin**		**Extra Warp**	
	Before Ageing	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**
Average	**62.60**	**63.20**	**72.00**	**68.60**	**77.00**	**76.00**	**78.00**	**79.40**
Standard Deviation	**1.67**	**0.84**	**1.41**	**1.52**	**0.71**	**1.00**	**0.71**	**1.52**
CV %	**2.67**	**1.32**	**1.96**	**2.21**	**1.28**	**1.32**	**0.91**	**1.91**
T-Test value	**0.250585**		**0.002391**		**0.070964**		**0.079967**	
% change in GSM	**-0.96**		**4.72**		**1.30**		**-1.79**	

At the same time, variations in yarn interlacement seem to be playing a role in assisting fiber degeneration. Satin weave displays marginal decrease in weight. Loss in weight is more profound in twill weave where the figure is close to 5% (Table 7). Considering that both plain weave and satin weave allow better movement of yarns within the fabric as compared to twill weave where yarns are placed in more interlocked manner, freedom of movement of yarns is indicated to hold key to the phenomenon. Plain weave with extra warp displays marginal increase in GSM, quite in line with plain weave fabric.

3.2.2 Tensile Strength:

Breaking Load **–** As observed in Table 8, breaking load in warp direction is highest in both satin weave and plain weave with extra warp. In the latter case, the reason clearly is the set of extra yarns that reinforce strength in that particular direction. It is seen that post ageing all weave variation settle at equivalent level in terms of strength. However, plain weave with extra warp suffers lesser loss in strength due to ageing, probably because of reinforcement provided by extra set of yarns. In weft direction, again satin weave exhibits highest tensile strength followed by twill and plain weave. However, post ageing results differ in all the weave variations. Thus, weft yarns are playing significant role in deciding the over-all strength parameters of the fabric. Also, it is evident that increased GSM is providing better strength to fabrics.

Extension - warp direction - the results show that pre ageing, plain weave and its extra warp variation exhibit highest extension %. This reinforces the explanation that yarn interlacement design plays significant role in determining tensile properties of a fabric.

Weft direction - Plain weave recorded highest extension % followed by satin weave and twill thereafter. The extra warp variation exhibits lowest extension % in weft direction. The results clearly indicated ease of movement of weft yarns as determining factor.

Comparison of change in Tensile Strength and Extension % between various Weaves:

Surprisingly, satin weave fared better in terms of breaking load in both warp and weft direction. Again, % loss in strength post ageing is highest in case of twill weave and satin weave. Alternatively, readings obtained for extension before break, conclude that plain weave is better equipped to address strain as compared to twill and satin weaves. This could be due to the simple nature of weave in their case. Pre ageing extension in weft direction is quite low in case of extra warp weave variation. This could be due to movement restriction provided by the extra set of warp yarns, although there is no published data available in this reference. This could be further supported by the fact that post-ageing, where all other weaves suffer loss in extension, extra warp variation in weft direction displays increase in extension up to 5%.

Table 8: Combined effect of Weaves and ageing on Breaking Load and Extension

	Weave Type	Plain		Twill		Satin		Extra Warp	
		Before Ageing	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**	**Before Ageing**	**After Ageing**
BREAKING LOAD (Warp) (N/m^2)	**Average**	**7.96**	**5.48**	**9.84**	**5.46**	**10.74**	**5.64**	**10.70**	**7.08**
	Standard Deviation	**0.67**	**0.60**	**1.16**	**0.77**	**0.88**	**0.33**	**1.48**	**0.86**
	CV %	**8.46**	**10.98**	**11.80**	**14.10**	**8.24**	**5.83**	**13.83**	**12.13**
	T-Test	**0.004566**		**0.000196**		**0.000194**		**0.002034**	
	% Change	**31.16**		**44.51**		**47.49**		**33.83**	
BREAKING LOAD (Weft) (N/m^2)	**Average**	**7.29**	**4.95**	**9.91**	**5.43**	**12.78**	**7.81**	**8.66**	**6.40**
	Standard Deviation	**1.02**	**0.50**	**1.37**	**0.66**	**0.45**	**0.36**	**0.16**	**0.48**
	CV %	**14.00**	**10.07**	**13.78**	**12.22**	**3.54**	**4.66**	**1.84**	**7.42**
	T-Test	**0.000350**		**0.000004**		**0.000000**		**0.000002**	
	% Change	**32.10**		**45.21**		**38.89**		**26.10**	
EXTENSION % (Warp)	**Average**	**13.00**	**5.33**	**8.00**	**5.00**	**9.00**	**5.00**	**14.33**	**6.67**
	Standard Deviation	**1.83**	**0.75**	**0.75**	**0.00**	**0.91**	**0.00**	**1.49**	**0.00**
	CV %	**14.04**	**13.98**	**9.32**	**0.00**	**10.14**	**0.00**	**10.40**	**0.00**
	T-Test	**0.000163**		**0.000422**		**0.000304**		**0.000163**	
	% Change	**7.67**		**3.00**		**4.00**		**7.67**	
EXTENSION % (Weft)	**Average**	**20.21**	**8.33**	**13.96**	**9.17**	**15.83**	**9.17**	**5.83**	**11.25**
	Standard Deviation	**3.01**	**0.00**	**1.24**	**0.89**	**1.26**	**0.89**	**1.26**	**1.73**
	CV %	**14.91**	**0.00**	**8.88**	**9.72**	**7.96**	**9.72**	**21.60**	**15.33**
	T-Test	**0.000005**		**0.000002**		**0.000000**		**0.000149**	
	% Change	**11.88**		**4.79**		**6.67**		**-5.42**	

These results can be explained by weakening and relaxation of extra set of warp yarns due to ageing. Also, loss in extension is lower in twill and satin as compared to plain weave, as they already displayed reduced capacity to extend before break. Thus, it is evident that twill weave fares low in terms of responding to stress-strain situation against damage, closely followed by satin weave. However, plain weave and weave with extra warp prove to be better equipped to handle stress and strain during care and display of artefacts.

3.2.3 *Abrasion Resistance:*

Table 9: Combined Effect of Ageing and Thread count on Abrasion Resistance in different Weaves of Cotton Fabric

		WEIGHT OF FABRIC (gms)					
		Before Ageing			After Ageing		
		Initial weight	Final weight	% change in weight	Initial weight	Final weight	% change in weight
PLAIN WEAVE (5500 cycles)	Average	0.095	0.073	23.61	0.093	0.063	32.50
	SD	0.005774	0.005000		0.005000	0.005000	
	CV %	6.077371	6.896552		5.405405	8.000000	
	T-Test	0.008850					
	Increase in weight loss	8.89					
TWILL WEAVE (5500 cycles)	Average	0.09	0.07	21.67	0.08	0.04	54.86
	SD	0.01	0.01		0.01	0.01	
	CV %	5.41	6.90		6.06	25.53	
	T-Test	0.002033					
	Increase in weight loss	33.19					
SATIN WEAVE (5500 cycles)	Average	0.09	0.07	21.67	0.10	0.05	46.39
	SD	0.01	0.01		0.01	0.01	
	CV %	5.41	6.90		5.13	18.24	
	T-Test	0.005268					
	Increase in weight loss	24.72					
EXTRA WARP PLAIN WEAVE	Average	0.10	0.08	17.50	0.10	0.05	50.00
	SD	0.00	0.01		0.00	0.02	
	CV %	0.00	11.61		0.00	36.51	
	T-Test	0.003267					
	Increase in weight loss	32.50					

It is interesting to note here that pre-ageing all weave variations display equivalent resistance to damage against abrasion, where extra warp variation exhibiting slightly better capacity to handle the same (Table 9). This can be attributed to reinforcement provided by extra set of warp yarns. However, loss in abrasion resistance property is non-uniform in various weaves, with twill weave suffering maximum loss, followed by extra warp variation and satin weave. Possibly, plain weave provides a balanced spatial arrangement which allows yarns to move to a certain extent, avoiding breakage. Satin weave provides too long floats to be safe against damage and twill weave allows little freedom of movement to yarns, so as to escape abrasion. In case of plain weave with extra warp, the spatial arrangement alternates between areas of balanced and tight weave, and tightly woven areas have suffered maximum damage adding up to total loss in mass due to abrasion. Thus, it can be concluded that post-ageing surface treatments need to be administered with caution in twill, extra warp variation and satin weave.

3.2.4 Flexural Rigidity:

It can be seen from Table 10 that Bending Length in extra warp variation and satin weave is highest and twill weave registers lowest bending length. In extra warp variation, the additional yarns are responsible for providing rigidity. At the same time, long floats in satin weave ensure undisturbed lengths of yarns adding its bit to yarn rigidity. In twill weave, the intricate interlacement makes yarn travel at various angles, thus leading to higher flexibility. Again, fabrics with higher rigidity tend to lose more after ageing. Also, it is interesting to note that post-ageing all fabrics reach almost similar statistics in terms of Bending Length and Flexural Rigidity. In fact, Plain and Twill weaves are able to maintain yarn rigidity better than satin and extra warp variation. Thus, it can be inferred that ageing impacts plain weave and twill weave to a lesser extent when it comes to retaining rigidity after ageing. Therefore, curators and conservators are expected to face lesser issues while trying to recreate the drape and fall of fabrics made in these weaves as compared to other weaves.

Table 10: Effect of Ageing and Weave variation on Bending Length and Flexural Rigidity of different weaves in Cotton Fabrics

	Sample No.	**Bending Length** (mm)			**Flexural Rigidity** (μjoule/m)		
		Before Ageing	**After Ageing**	**% Change**	**Before Ageing**	**After Ageing**	**% Change**
PLAIN WEAVE	Warp Average	**2.68**	**1.50**	**44.15**	**0.00000175**	**0.000000323**	**81.54**
	Weft Average	**1.59**	**0.78**	**50.79**	**0.00000036**	**0.000000049**	**86.30**
TWILL WEAVE	Warp Average	**2.26**	**1.24**	**45.09**	**0.00000125**	**0.000000207**	**83.44**
	Weft Average	**1.37**	**0.66**	**51.71**	**0.00000027**	**0.000000029**	**89.24**
SATIN WEAVE	Warp Average	**2.700**	**1.022**	**62.15**	**0.00000220**	**0.000000125**	**94.30**
	Weft Average	**1.497**	**0.709**	**52.61**	**0.00000039**	**0.000000042**	**89.47**
EXTRA WARP WEAVE	Warp Average	**2.753**	**1.056**	**61.63**	**0.00000236**	**0.000000140**	**94.07**
	Weft Average	**1.769**	**0.791**	**55.30**	**0.00000063**	**0.000000059**	**90.59**

3.2.5 Change in Colour:

As evident from the Table 11, the whiteness of all weaves has decreased, and yellowness has increased after ageing. However, both Satin and Extra Warp variation seem to have suffered more loss in whiteness and higher increase in yellowness as compared to Plain and Twill variations. This could be due to more exposure of yarns in the former weaves, owing to the nature of interlacement of yarns in them.

Table 11: Effect of Ageing and Weave variation on Color properties of Cotton Fabric

		R	G	B	X	Y	Z	L	A	B	WI	TI	YI
PLAIN WEAVE	**Before Ageing**	200.00	197.00	164.00	58.67	54.46	20.10	73.79	2.40	10.25	(-) 179.00	(-) 63.36	97.75
	After Ageing	201.00	196.00	154.00	59.84	55.01	18.27	74.17	3.75	12.74	(-) 193.37	(-) 68.69	103.37
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							2.86	0.37	1.35	2.49	14.37	5.33	(-) 5.61
TWILL WEAVE		**R**	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**
	Before Ageing	209.00	207.00	170.00	65.35	60.75	22.46	77.95	2.31	10.78	(-) 172.60	(-) 62.83	97.47
	After Ageing	201.00	196.00	156.00	59.68	54.85	18.64	74.06	3.77	12.21	(-) 190.12	(-) 68.34	102.51
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							4.39	(-) 3.88	1.45	1.43	17.53	5.51	(-) 5.04
		R	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**

	Before Ageing	211.00	209.00	173.00	66.47	61.95	23.45	78.71	1.96	10.27	(-) 167.91	(-) 61.49	96.10
	After Ageing	202.00	196.00	153.00	60.78	55.68	18.35	74.62	4.24	12.99	(-) 193.41	(-) 70.03	104.16
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**dYI**
							5.41	(-) 4.08	2.27	2.72	25.50	8.54	(-) 8.06
EXTRA WARP WEAVE		**R**	**G**	**B**	**X**	**Y**	**Z**	**L**	**A**	**B**	**WI**	**TI**	**YI**
	Before Ageing	212.00	210.00	176.00	67.20	62.72	24.23	79.19	1.77	9.78	(-) 163.98	(-) 60.61	95.01
	After Ageing	204.00	199.00	157.00	62.01	57.03	19.28	75.52	3.73	12.57	(-) 188.79	(-) 68.21	102.62
							dE	**dL**	**dA**	**dB**	**dWI**	**dTI**	**Dyi**
							5.01	(-) 3.67	1.96	2.79	24.81	7.60	(-) 7.62

Summarizing the analysis of weave variations, it can be fairly concluded that Plain weave fairs better to ageing than other counterparts. Contrary to the common notion of Twill weave being the strongest, it doesn't fare that well, while responding to ageing against all parameters. Unlike other weave variations, Twill weave is susceptible to loss in matter after 20yrs of ageing, Tensile Strength loss is highest post-ageing and so is its capacity to resist abrasion. Also, it loses more rigidity than other weave variations and yellows faster because of ageing. Thus, Conservators and Curators need to be most cautious while working with aged Twill weaves as compared to other kind of weaves. Plain weave does not seem to be affected much after 20yrs of ageing and Satin weave and Extra weave variation suffer damage lower to Twill weave but higher than Plain weave post-ageing.

IV. CONCLUSIONS

- Data obtained has established that increase in yarn density in a fabric is directly proportional to increase in their strength. Thus, close woven fabrics can be expected to show comparatively better resistance to stress causing situations like hanging displays and loose weave fabrics are often comparatively lower in strength both pre and post ageing. Similarly, high thread-count fabrics suffer slightly more in terms of losing original drape and fall after ageing. However, the three thread-counts show similar weight change and colour change due to ageing. Thus, it can be concluded that close weaves are expected to pose lesser challenges to care-takers when it comes to procedures involving stress-and strain situations, like handling and abrasion during cleaning, display & storage procedures. However, ageing is expected to pose greater damage to original drape and fall of fabrics with close weaves as compared to open weave fabrics.
- The data generated brings us to an important observation that, Twill weave, considered to be strongest in regular use, proves to be most fragile post ageing. This can be attributed to closely packed yarns in Twill weave that do not leave enough room for expansion and contraction associated with periodic changes in temperature and humidity. Plain weave and Plain weave with extra yarn can be safely considered as most resistant to ageing related changes in strength and performance characteristics. Interestingly, Aged Satin weave maintains better strength and performance parameters post ageing as compared to Twill weave.

REFERENCES

[1]. Kaynak, H. K. and Topalbekiroglu, M., 2008, 'Influence of Fabric Pattern on the Abrasion Resistance Property of Woven Fabrics', *Fibres & Textiles in Eastern Europe, Vol. 16, No. 1, pg. 54-56.*

[2]. Cardamone, J. M., 2000, 'Historic Textiles and Paper', *In Historic Textiles, Papers and Polymers in Museums, ACS Symposium Series; American Chemical Society; Washington D.C., pg. 2-7.*

[3]. Pan, N., 1996, 'Analysis of Woven Fabric Strengths: Prediction of fabric Strength Under Uniaxial and Biaxial Extensions", *Composites Science and Technology, Vol. 56, pg. 311-327.*

[4]. Sachdeva. K., Suri, M. & Bhagat, S., 2011, 'Assaying Changes in Museum Textiles on Ageing – A Short Note', *Conservation of Cultural Property in India, Vol. 39, pg. 119 – 122.*

[5]. Feller, R.L., 1994, *Accelerated Ageing-Photochemical and Thermal Aspects, Research in Conservation,* The Getty Conservation Institute, The J. Paul Getty Trust.

[6]. Evenson, J. and Crews, P. C., 2005, 'The Effects of Light Exposure and Heat-Ageing on Selected Quilting Products Containing Adhesives', *Journal of the American Institute of Conservation, Vol. 44, No. 1, pg. 27-38.*

Standards used in the study

- AATCC Test Method 26-1994, 1995, 'Ageing of Sulphur-Dyed Textiles: Accelerated', AATCC Technical Manual, Vol.70, pg. 80-81.
- ASTM INTERNATIONAL, 'Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)', ASTM D 5034-09, ASTM International, PA, United States.
- ASTM INTERNATIONAL, 'Standard Test Method for Abrasion resistance of Textile Fabrics', ASTM D 4966-10, ASTM International, PA, United States.
- ASTM INTERNATIONAL, 'Standard Test Method for Stiffness of Fabrics', ASTM D 1388-08, ASTM International, PA, United States.
- ASTM INTERNATIONAL, 'Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates', ASTM E 313-00 ASTM International, PA, United States.

KANIKA SACHDEVA, et. al. "Effect of Fabric Construction on the Longevity of Aged Cotton Fabric." *International Journal of Engineering Research and Applications (IJERA),* vol.10 (09), 2020, pp 49-61.