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Role of Fibre in Degeneration of Aged Fabrics in Museums

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Abstract: Degeneration of fabrics with age is an accepted phenomenon. Limited data is available about impact of fiber characteristics on ageing of fabrics in museum settings. Museum professionals have relied on their personal experience and case studies while taking decisions about sensitive textiles. However, lack of established data can become a major hurdle in technological advancements in field of conservation science. Quantification of change in strength and performance parameters of a fabric with time and verified data about difference in the level of impact between fabrics made of different fibers can provide new perspectives to conservation and exhibition research approach. In present research, impact of ageing on strength and performance parameters of fabrics made of cotton, wool and silk has been analyzed since most museum collections primarily consist of these three natural fibers. Each fabric has been individually examined for select strength and performance parameters before and after accelerated ageing. Standardized testing procedures have been followed for ageing simulation, and testing of tensile strength, GSM (gram per square meter), abrasion resistance, flexural rigidity, and color change in fabrics. Results generated by this comparative assessment provide insights about difference in degree of vulnerability to ageing and its implications on museum procedures. The numeric data obtained can be construed and utilized in innumerable ways for devising technologically advanced equipment and procedures assisting in suitable cleaning, storage, exhibition and conservation strategies for museum fabrics.

Keywords: Accelerated Ageing, Data driven technologies, Deterioration, Degeneration, Museum Textiles, Natural fibers.

I. INTRODUCTION

Historical textiles possess unparalleled interpretational value. Museums play important role in this process of historical education by storing, curating, restoring and exhibiting these storehouses of information. However, textiles being organic in nature pose constant challenges by degrading at a fast pace. Invariably, best practices in exhibition, storage and curation help increasing lifespan of an artefact. Conservation scientists need to continuously predict further behavior of the artefacts in their collection, in order to avoid damage. Therefore, in order to understand the useful lifetime of a product, it is imperative to understand its process of ageing [1]. Additionally, novel data-driven technologies have been facilitating advancement in disciplines across the globe. Established scientific data is the key to utilization of these technologies for developing higher precision devices and algorithms for advancement of conservation science. Therefore, it is important to map the behavior of substrates with the passage of time. Majority textile collection of our museums comprise of natural fibers like silk, wool, cotton etc. It has been noted in the pilot study conducted in this research that Cotton, Wool and Silk form the largest part of the textile collection in most museums. Curators face a variety of challenges while maintaining artefacts made of these fibers as each have their own characteristics and susceptibility. Therefore, it is imperative to investigate and map the relationship between a fiber's intrinsic characteristics and its impact on degeneration.

Although, first experimental work on the objective measurement of fabric's mechanical properties dates back to the 1930s, use of analytical chemistry in museum laboratories happened much later [2]. Limited research is available on direct relationship between fibre chemistry and its degeneration, though, there are secondary references available as elaborated further. In her landmark book on conservation of museum objects, Sheila Landi noted that, 'the study of textile chemistry shows that the strength of fibres and their resistance to ageing can be proportionately related to the length and compactness of the molecular chains of which they are made [3]. It has been noted by conservation scientists that the bio deterioration of cellulosic fibres results in a reduction of the polymerization degree and thus a textile strength loss. Further, larger the diameter of the fibre, the better its resistance to photo degradation, as less radiation penetrates into the interior. It follows that one of the reasons that silk is the most fragile fibre under light exposure is the fact that it is the finest natural fibre [4]. Another study explained that breakdown of cellulose, results from the action of cellulolytic enzymes produced by arrange of bacteria and, especially, fungi. A principle effect of cellulolytic enzymes is that it decreases the degree of polymerization of the long-chain cellulose molecules, so that fibre structure is impaired and fibre strength decreased [5]. However, there is limited literature available in textile industry or conservation science that can systematically map the change in strength and performance parameters of a fabric substrate over the period of time. This data can find huge applications in the field of data driven technologies like creating algorithms and calibration of advanced high precision instruments.

II. METHODOLOGY

A. Procedure

Three selected natural fibres, i.e., cotton, wool and silk were selected for the study due to their presence in museum collection in large volumes. The fabrics made of these selected fibres for the experiments was developed at the Weavers Service Centre, Bangalore, India. The experiment was designed to test the degree of change in strength and performance parameters of fabrics before and after simulated ageing. Therefore, experimental fabric samples were tested for selected strength and performance parameters before and after ageing. Standardised accelerated ageing procedure was followed to simulate the museum textiles that are very old, made of different weaves and are kept in either storage or displayed in museums. Accelerated ageing conditions were kept constant for all the three fabrics (process elaborated in section D). Thus, quantitative data established by standardised procedures was obtained on the extent of change each fibre undergoes after degeneration due to ageing.

B. Sample Selection

As per the information collected in the pilot phase of research, cotton and silk samples were developed in plain weave and wool samples were selected from twill weave. It is worthwhile mentioning here that pilot phase of this study was conducted in 14 museums spread across India, Australia & USA. During the pilot phase, conservators and curators of the selected museums were interviewed with the help of an open-ended questionnaire. The responses provided by these experts formed the basis of various constants and variables selected for this research. The specifications of fabric samples are as in Table 1.

Table 1: Fabic Specifications

S. No	Fibre	Color	Weave	GSM
1.	Cotton	White	Plain	80X70
2.	Wool	Off-White	Twill	55X54
3.	Silk	White	Plain	120X95

C. Testing Parameters

For quantitative evaluation, specific 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 three selected fibres were tested and compared for following parameters:

1) *Fabric Weight:* Grams per Square Meter (GSM) of the fabric samples is calculated for determining the mass of fabrics before and after accelerated ageing. 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:* Change in tensile strength is the foremost indicator of modification in fabric strength and therefore longevity. To test the tensile Strength of fabric before and after ageing, Grab Test- ASTM D 5034-09 was used. Values for the breaking force and the elongation of the test specimen were obtained. From each laboratory sample, specimens from the warp direction and filling direction were taken as per the procedure prescribed in the standardised test. Also, SD and CV% was duly calculated for statistical analysis.
3) *Abrasion Resistance:* Museum properties are displayed and stored in a manner that artefacts face minimum abrasion, some amount of it is inevitable. Thus, propensity to surface damage due to abrasion is an important determinant of how much a fabric can be handled for cleaning, storage, display and even research purposes. Usually the surface wear-off due to abrasion happens because of loss of fiber matter from the surface of the fabric. Thus, a weakened fabric would result in loosened yarns and fragmented polymer chains lying on the surface of the fiber, which would readily erode on incidence of abrasion, further weakening the fabric.

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. However, it was realized that number of cycles that could bring measurable change in mass were different for different fabrics. Based on the pilot study conducted on the samples, it was found that cotton and silk samples suffered measurable loss at 5500 cycles, which was then taken as standard for them. However, wool was run on the machine for 12,500 cycles to achieve dimension of measurable loss. 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.
Average readings of abrasion resistance were compared and additionally, SD and CV% was calculated for statistical analysis.

4) *Flexural Rigidity:* Flexural Rigidity is a measure of stiffness of textile fabrics and stiffness is resistance to bending. The draping qualities of fabrics are related to fabric stiffness [6]. 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.
As per the standard, 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 method provides 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
The relationship between CIE XYZ values and the x, y chromaticity coordinates is as follows:
Y = CIE Tristimulus Y (as above)
x = X/(X +Y + Z)
y = Y/(X + Y + Z) (http://www.hunterlab.com/manuals/cfchapter10_2_4.pdf)

D. 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.[7],[1] 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 [8]
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, (Plate-A). 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. Procedure: Alternate Oven Test: 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. The placement of samples in the oven was such that no part of the sample touched metallic body of the oven (Plate-B). 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

Data obtained in this research revealed interesting patterns about the differences in deterioration pattern of silk, wool and cotton.

A. Fabric Weight

1) *Comparison of change in GSM between Cotton, Wool and Silk:* Mapping the changes in GSM would contribute in better understanding of the process as excessive loss in GSM can be viewed as reduction in strength, durability and dimensions of the fabric. As evident from the Table 2, no weight loss was observed in cotton fabric after ageing equivalent to 20years of time. However, slight increase in GSM was evident. This can be attributed to slight shrinkage happening in the fabric in the presence of moisture and intense heat. 'Shrinkage is due to the formation of many new hydrogen secondary bonds between neighboring cellulose chains on drying' (Balazy, 2002) [9]. It is evident from Table 2 that although cotton and wool lose nil or negligible weight in accelerated ageing equivalent to 20years, silk readily loses approximately 1/8th (12.38%) of its weight within the same timeframe.
2) *Discussion: Nil or* negligible loss of weight in cotton and wool does not reflect non-degeneration of fibers at molecular level. There is a possibility that degraded molecu1les are present on the surface of the aged fabric, which would readily erode in first treatments thereafter. It certainly implies that the two fibers have not reached that stage of deterioration where damaged molecules break apart from the structure of the fiber. However, in case of silk, reduction of weight by 1/8th of the original reflects an advanced stage of degradation. Thus, degradation of silk happens much faster than cotton or wool, given the three fabrics are exposed to similar circumstances. In museum textiles more careful handling is needed for artefacts made of silk as compared to cotton and wool.

Table 2: Effect Of Ageing On Gsm Of Cotton, Wool And Silk

FIBRE	GSM (gms)					
	COTTON		WOOL		SILK	
Sample No.	Before Ageing	After Ageing	Before Ageing	After Ageing	Before Ageing	After Ageing
S-1	64.00	64.00	166.00	165.00	43.00	36.00
S-2	60.00	62.00	170.00	168.00	42.00	39.00
S-3	62.00	64.00	163.00	165.00	42.00	36.00
S-4	64.00	63.00	169.00	167.00	42.00	36.00
S-5	63.00	63.00	172.00	167.00	41.00	37.00
Average	62.60	63.20	168.00	166.40	42.00	36.80
SD	1.67	0.84	3.54	1.34	0.71	1.30
CV %	2.67	1.32	2.10	0.81	1.68	3.54
T-Test	0.250585		0.113588		0.001052	
% change in GSM	-0.96		0.95		12.38	

B. Tensile Strength

1) *Cotton:* It can be seen from Table 3 that almost 1/3rd of the fiber strength in warp direction is lost after accelerated ageing. The loss in extension % is however around 8%. Although, this result does not directly imply that almost 1/3rd of the molecular chains of cellulose have been damaged, it certainly reflects the extent of strength loss a cotton fabric is expected to undergo with 20 years of age. The loss in tensile strength & extensibility is much higher in warp direction as compared to weft direction. As expected, the initial extension (before ageing) in weft yarns was higher as compared to warp yarns. This is a common characteristic of any plain weave fabric, attributed to higher twist and lower tension in weft yarns.

2) *Wool:* As evident from Table 3, wool sustains negligible strength loss in the warp direction. Also, extension in warp direction has marginally increased after accelerated ageing. The negligible loss in the strength reflects the fact that the cuticle of wool fiber has not been damaged after accelerated ageing. As per the information collected in literature review, wool fiber is saved from damage due to deterioration till the time its cuticle is intact. The process of deterioration in wool initiates with rupture of di-sulphide linkages followed by damage to cuticle and then chain incision. Thus, ageing close to 20years is not enough to cause considerable damage to strength. However, increased elongation before break reflects breakage of disulphide linkages thus, initiating the process of deterioration. Unlike warp, in weft direction wool suffers about 10% loss in strength and decrease in elongation before break is also near to 5%, which is higher than that in warp direction. Increased reduction in strength and elongation in weft direction implies that wool suffers greater impact of deterioration in weft direction as compared to warp direction. This can be attributed to the yarn preparation differences in warp and weft direction.
3) *Silk:* It is evident from the readings (Table 3) that silk performs better in terms of tensile strength than cotton , possibly because of its highly crystalline structure. However, the loss in tensile strength after ageing is also high as silk desiccates and becomes brittle in the presence of high heat which in turn initiates free thermal oxidation of polymer chains (Landi, 1985) as noted in the review section. This explains the reduction in strength to the extent of 23 % after ageing. Readings denote that loss in strength in weft direction is slightly higher than that in warp direction although loss in extension is negligible. Thus, it can be concluded that aged silk stands considerably weaker than unaged silk.

Table 3: Effect of Ageing On Tensile Strength Of Cotton, Wool And Silk

		Warp Breaking Load (N/m^2)		Warp Extension %		Weft Breaking Load (N/m^2)		Weft Extension %	
	Sample No.	Before Ageing	After Ageing	Before Ageing	After Ageing	Before Ageing	After Ageing	Before Ageing	After Ageing
COTTON	S-1	7.00	5.90	15.00	6.67	6.90	5.10	16.67	8.33
	S-2	8.80	4.60	13.33	5.00	8.90	5.20	25.00	8.33
	S-3	8.30	5.90	13.33	5.00	8.20	5.60	16.67	8.33
	S-4	8.00	5.10	10.00	5.00	6.00	4.90	23.33	8.33
	S-5	7.70	5.90	13.33	5.00	7.80	4.10	21.67	8.33
	S-6	-	-	-	-	7.50	4.40	20.00	8.33
	S-7	-	-	-	-	7.00	4.90	18.33	8.33
	S-8	-	-	-	-	6.00	5.40	20.00	8.33
	Average	7.96	5.48	13.00	5.33	7.29	4.95	20.21	8.33
	SD	0.67	0.60	1.83	0.75	1.02	0.50	3.01	0.00
	CV %	8.46	10.98	14.04	13.98	14.00	10.07	14.91	0.00
	T-Test	0.004566		0.000163		0.000350		0.000005	
	% Change	31.16		32.08		7.67		11.88	
WOOL	S-1	20.50	20.70	16.67	16.67	14.30	12.00	30.00	33.33
	S-2	22.50	21.10	13.33	16.67	14.00	12.10	33.33	33.33
	S-3	21.70	21.70	13.33	16.67	13.60	11.90	25.00	30.00
	S-4	21.10	22.40	13.33	16.67	13.20	11.90	26.67	33.33
	S-5	22.20	20.20	15.00	16.67	13.10	11.20	25.00	26.67
	S-6	-	-	-	-	12.30	12.10	25.00	33.33
	S-7	-	-	-	-	12.50	12.40	25.00	33.33
	S-8	-	-	-	-	13.00	11.60	26.67	30.00
	Average	21.60	21.22	14.33	16.67	13.25	11.90	27.08	31.67
	SD	0.81	0.86	1.49	0.00	0.69	0.36	3.05	2.52
	CV %	3.76	4.05	10.40	0.00	5.21	3.05	11.28	7.96
	T-Test	0.277383		0.012448		0.00104		0.001908	
	% Change	1.76		-2.33		10.19		-4.58	
SILK	S-1	20.60	13.80	18.33	15.00	28.40	20.40	25.00	25.00
	S-2	20.10	16.10	16.67	15.00	26.60	23.80	20.00	20.00
	S-3	19.70	16.00	18.33	15.00	34.40	19.80	25.00	20.00
	S-4	20.20	14.20	18.33	15.00	29.40	19.20	20.00	20.00
	S-5	19.60	16.50	18.33	15.00	30.70	21.20	25.00	20.00
	S-6	-	-	-	-	29.40	21.60	18.33	16.67
	S-7	-	-	-	-	30.60	21.90	20.00	20.00
	S-8	-	-	-	-	27.90	22.00	20.00	20.00
	Average	20.04	15.32	18.00	15.00	29.68	21.24	21.67	20.21
	SD	0.40	1.23	0.75	0.00	2.35	1.45	2.82	2.26
	CV %	2.01	8.01	4.14	0.00	7.91	6.81	13.00	11.19
	T-Test	0.001345		0.000422		0.000339		0.055389	
	% Change	23.55		31.10		3.00		1.46	

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Volume 9 Issue I Jan 2021- Available at www.ijraset.com

a) *Comparison of Tensile Strength and Extension in Cotton, Wool and Silk:* As evident from Table 3, wool suffers negligible loss in breaking load after 20years of ageing. The next is silk with almost 1/4th loss in breaking load whereas cotton loses almost 1/3rd of its breaking strength. Also, out of the three fabrics cotton faces maximum loss in extensibility. Where loss in extensibility is minimal in silk, wool shows a reverse phenomenon. Thus, cotton stands weakest of the three fabrics as far as reduction in strength is concerned. This can be attributed to breakage of weak hydrogen bonds and reduction in Degree of Polymerization of cellulose polymer. Also, loss in elongation before breakage is highest in case of cotton, as cross-linking and chain scission due to thermal oxidation result in a rigid and fragile material. With reference to handling of museum textiles, it is implied that of the three, cotton fabrics need maximum care in stress /strain conditions like stretching over a frame for display or cleaning. This observation will also have implication on selection of conservation stitches used for mending snips and cuts as new threads apply considerable strain on the adjoining aged yarns of the fabric. Thus, aged cotton artefacts would be most sensitive to intervention with stitches. However, the observations also help us conclude that cotton artefacts are more fragile for hanging displays as they lose their capacity to hang under their own weight due to loss of extensibility and breaking load. Thus, lengthy cotton artefacts are more likely to suffer damage in hanging / roller displays as compared to their silk and wool counterparts.

C. Abrasion Resistance

1) *Cotton (5500 cycles):* It can be seen from the Table 4 that almost 9% more matter is lost from the fabric surface, after accelerated ageing. This loss in matter certainly reflects weakening of the fabric due to degeneration. Also, it implies that 20years of ageing renders a cotton fabric more susceptible to any kind of abrasion.
2) *Wool (12,500 cycles):* It was seen that wool demonstrated negligible weight loss till 10,000 cycles of abrasion and thereafter, the loss in weight suddenly mounted to 38 %. This implies that up to 10,000 cycles, the fibre was able to maintain the cuticle strength and abrasions whereas beyond this point the cuticle ruptured and damage to the fiber from abrasion was accelerated. Thus, it can be concluded that weathering due to abrasion in wool is a combination of both, fabric age and the strength and amount of abrasion the artefact suffers.
3) *Silk (5500 cycles):* Table 4 denotes that silk suffered almost 3 times more loss in weight after similar number of cycles as compared to cotton. Thus, it can be concluded that susceptibility of silk to abrasion intensifies after 20years of age. Therefore, silk artefacts beyond this age need to be provided care with minimum handle and abrasion in cases of restoration, display and storage.

Table 4: Effect of Ageing And Thread Count On Abrasion Resistance Of Cotton, Wool And Silk

FIBRES	Sample No.	WEIGHT OF FABRIC (gms)					
		Before Ageing			After Ageing		
		Initial weight	Final weight	% loss in weight	Initial weight	Final weight	% loss in weight
COTTON (5500 cycles)	S-1	0.10	0.08	20.00	0.10	0.07	30.00
	S-2	0.09	0.07	22.22	0.09	0.06	33.33
	S-3	0.09	0.07	22.22	0.09	0.06	33.33
	S-4	0.10	0.07	30.00	0.09	0.06	33.33
	Average	0.095	0.073	23.61	0.093	0.063	32.50
	SD	0.01	0.01		0.01	0.01	
	CV %	6.078	6.90		5.41	8.00	
	T-Test	0.008850					
	Weight loss change post ageing	8.89					
WOOL (12,500 cycles)	S-1	0.2	0.16	20	0.2	0.08	60
	S-2	0.2	0.15	25	0.2	0.08	60
	S-3	0.19	0.15	21.05	0.2	0.08	60
	S-4	0.21	0.17	19.05	0.2	0.08	60
	Average	0.20	0.16	21.28	0.20	0.08	60
	SD	0.01	0.01		0.00	0.00	
	CV %	4.08	6.08		0.00	0.00	
	T-Test	0.000042					

	Weight loss change post ageing	38.72					
SILK (5500 cycles)	S-1	0.05	0.04	20	0.05	0.02	60
	S-2	0.04	0.03	25	0.04	0.02	50
	S-3	0.05	0.04	20	0.04	0.02	50
	S-4	0.05	0.04	20	0.04	0.02	50
	Average	0.05	0.04	21.25	0.04	0.02	52.5
	SD	0.01	0.01		0.01	0.00	
	CV %	10.53	13.33		11.76	0.00	
	T-Test	0.001085					
	Weight loss change post ageing	31.25					

a) *Comparison of change in Abrasion Resistance between Cotton, Wool and Silk:* Comparing the weight loss values due to abrasion in three fibers, brings about interesting trends. It was noted that both cotton and silk lose approximately similar % weight before ageing. However, post ageing, loss in weight in silk is almost 3 times higher as compared to cotton. At the same time, the parameters in wool remain almost unaltered till this level of abrasion pre- and post-ageing. Thus, it can be concluded that silk becomes most sensitive to abrasion after ageing and needs to be handled more carefully for surface treatments as compared to cottons of the same age. In wool, it has been seen the loss due to abrasion is more of a function of strength and duration of abrasion, thus higher amounts of abrasion bring about similar loss in fresh fabrics as cotton and silk. Therefore, it can be safely concluded that aged silk fibers are most unsuitable for abrasion-based treatments like sponge cleaning as compared to cotton and wool artefacts.

D. Flexural Rigidity

Change in Flexural Rigidity would have a long-lasting impact on the display capability of a textile artefact as the drape and fall of a textile would not remain the same if the former changes drastically. Also, a sharp increase in stiffness would result in higher chances of fiber breakage during bending.

Table 5: Effect Of Ageing On Bending Length And Flexural Rigidity Of Cotton, Wool And Silk

Fibre	Sample No.	Bending Length (mm)			Flexural Rigidity (μjoule/m)		
		Before Ageing	After Ageing	% Change	Before Ageing	After Ageing	% Change
COTTON	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	86.3
WOOL	Warp Average	1.09	1.08	1.43	0.000000312	0.000000324	-3.65
	Weft Average	0.83	0.82	1.50	0.000000139	0.000000134	3.00
SILK	Warp Average	0.89	0.81	4.29	0.0000000422	0.0000000283	24.30
	Weft Average	1.06	1.06	-0.29	0.0000000735	0.0000000649	11.73

1) *Cotton:* It has been observed (Table 5) that post ageing, bending length in cotton decreases to almost half of the original and flexural rigidity is decreased by approximately 80%, more so in weft direction. This implies that 20years of ageing brings the fabric to a stage of extreme pliability and decreased strength where possibly the fiber structure has not degraded to extreme but secondary bonding have given way.
2) *Wool:* As evident from parameters studied previously, wool doesn't seem to have undergone significant change after 20years of ageing. The bending length and flexural rigidity of the fiber have been affected only marginally. This implies that degradation is still on superficial level in wool post ageing and a wool artefact of thus age could be comfortable displayed in various drapes and forms.
3) *Silk:* Readings obtained in Table 5 demonstrate marginal decrease in bending length of silk fibers after ageing which translates into approximately 24% increase in rigidity in warp direction and 10% increase in rigidity in weft direction. This implies significant loss in drape and fall characteristics of silk fabric after 20years of ageing.

a) *Comparison of change in Flexural Rigidity in Cotton, Wool and Silk:* Theoretically, the stiffness of fibers should increase once they have reached a stage of high degeneration. This primarily happens due to desiccation and reduced ability to absorb moisture, once the fibers are extremely degraded. Alternately, there is an intermittent state of higher flexibility when the secondary bonds securing the fiber structure break and permit higher movement. The comparison of Bending Length and Flexural Rigidity values of the three fibers shows clear differences in their performance properties post ageing. It can be seen that cotton deviates the most from its original drape and fall after ageing. Silk fiber also demonstrates considerable change in stiffness, more so in the warp direction. However, wool proves to be strong enough to demonstrate its original drape and fall post ageing. Thus, Mannequin display of cotton costumes could prove more challenging as compared to costumes of silk and woolen costumes.

E. Whiteness Index

Color is an important property of a textile material, which decides both, its functional and aesthetic characteristics. In the given tables, components of color were measured before and after ageing and final inference drawn in terms of Whiteness Index (WI), Tint Index (TI) and Yellowness Index (YI).

1) *Cotton:* A clear shift can be seen in the color coordinates as depicted in the Table 6. The Whiteness Index in cotton reduced by about 14 points and the Yellowness Index increased by 5-6 points. The change clearly indicates an increase in yellowness of cotton fabric post-ageing.
2) *Wool:* Here again, the coordinates demonstrate a clear shift from its value prior to ageing. The whiteness Index decreases by 23 points and Yellowness Index further increases by approximately 9 points, confirming increased yellowness in fabric post-ageing.
3) *Silk:* The definite shift in co-ordinates confirms change in color post-ageing. The Whiteness in this case decreases by approximately 6 points and yellowness increases by 2 points, suggesting mild increase in yellowness of the fabric post ageing.

a) *Comparison of change in Color between Cotton, Wool and Silk:* Change in color is an indicator of structural changes happening in the fiber molecule. Often, deterioration by-products create a layer on the surface of the fabric which then makes the fabric look yellowed or discolored. Desiccation and embrittlement of fiber material might also lead to yellowness in a fabric. Also, fabric discoloration alters the aesthetic properties of the fabric, leaving it less appealing for use and display.

Table 6: Effect Of Ageing On Color Properties For Cotton, Wool And Silk

		R	G	B	X	Y	Z	L	A	B	WI	YI
COTTON	Before Ageing	200.00	197.00	164.00	58.67	54.46	20.10	73.79	2.40	10.25	(-) 179.00	97.75
	After Ageing	201.00	196.00	154.00	59.84	55.01	18.27	74.17	3.75	12.74	(-) 193.37	103.37
							dE	dL	dA	dB	dWI	dYI
							2.86	0.37	1.35	2.49	14.37	-5.61
WOOL		R	G	B	X	Y	Z	L	A	B	WI	YI
	Before Ageing	209.00	223.00	126.00	73.35	71.31	16.40	84.45	(-) 4.34	22.17	(-) 231.97	107.41
	After Ageing	209.00	212.00	107.00	66.66	62.51	11.89	79.06	1.08	23.55	(-) 255.15	116.90
							dE	dL	dA	dB	dWI	dYI
							7.76	-5.38	5.42	1.38	23.18	-9.49
SILK		R	G	B	X	Y	Z	L	A	B	WI	YI
	Before Ageing	206.00	230.00	151.00	76.81	76.98	22.29	87.74	(-) 9.14	18.39	(-) 201.48	96.55

	After Ageing	212.00	227.00	156.00	76.02	74.32	22.36	86.21	(-) 5.28	17.20	(-) 195.67	98.51
							dE	dL	dA	dB	dWI	dYI
							4.32	(-) 1.53	3.86	(-) 1.19	(-) 5.81	(-) 1.96

It can be seen from Table 6 that wool has the greatest loss in Whiteness Index and increase in Yellowness Index, followed by cotton and thereafter silk. Thus, it can be safely concluded that aesthetically, wool suffers the most by ageing and silk suffers minimum aesthetic damage in case of ageing up to 20years.

IV. CONCLUSIONS

Results obtained from the experiments conducted during this research bring us to the conclusions that ageing of cotton, wool and silk fabrics do not follow similar patterns. Woollen artefacts within 20 years of age span, can be safely subjected to standardized cleaning, restoration and exhibition processes suitable for un-aged woollen textiles. However, most woollen items museum collections can demonstrate considerable discolouration in a span of two decades and beyond. Therefore, aesthetics-based research of woollen artefacts needs to be carefully conducted, factoring in the discolouration resulting from ageing. Aged silk artefacts in museums can be extremely sensitive to cleaning and restoration treatments and standardized cleaning practices for standard silk fabrics might not deem suitable for aged silk fabrics, particularly sponging. However, aesthetic characteristics of silk artefacts like colour are largely unaffected after two decades of lifetime. It is important here to note that aged cotton artefacts might not be suitable for exhibition formats that lay emphasis on the drape of the textile as the drape might have got impacted by ageing. Like silk, cotton textiles are equally susceptible to age-related degeneration. Cotton textile artefacts can prove to be most unsuitable for hanging / vertical display designs where fabric stretches under its own weight. Therefore, greater care needs to be taken in handling of aged silk and cotton artefacts in exhibition and storage as drape and fold line damages should be expected to be more profound as compared to wool. While concluding, it is important here to note that the deterioration pattern is different for different fibres when mapped across the same timespan & degeneration environment. Therefore, artefacts made of these fibres need highly personalised process-maps as per their individual susceptibility. Conservators have been working hard to slow down this process by careful methods of storage, display and repair, conserve the object in a state which provides both information and enjoyment. Availability of carefully mapped degeneration data can begin a new era in the field of heritage conservation by assisting conservators and curators with tools and algorithms based on data driven technologies, that has added precision in almost every other discipline.

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