THE DEGRADATION EVIDENCE OF NATURAL AND SYNTHETIC FIBERS

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Abstract: *Based on their chemical composition, fibres belong to two main groups: the natural cellulose-, and protein-based materials; and the natural-based and synthetic-based artificial textile materials. The physical and chemical properties of the fibres determine their future behaviour in a different environment. Their damage results from the physical, chemical, and biological interactions between the fabric and its surroundings. There is clear evidence of the degradation of the several hundred years old natural fibres. Still, at the same time, the twentieth-century objects are often said to be "time bombs" waiting to explore in museum collections. It is becoming evident that these modern materials show signs of breakdown, sometimes dramatically and rapidly. Since they are only barely a hundred years old, there is not enough data concerning their long-term future behaviour. However, there is a burning need in conservation to examine the deterioration factors of the different artificial threads to preserve them as much as possible for posterity. Future work will be based on the aging tests of artificial textiles to predict their future behaviour and determine their optimal environmental limits for preventive conservation. In this paper, we will try to give a short overview of the most important damage factors and their effects on textiles that should be considered during storage and exhibition.*

Keywords: *natural fibres, synthetic fibres, degradation, artificial aging tests*

INTRODUCTION

All organic objects, but especially objects made of textile, are very sensitive to their environment. They can be damaged easily, and therefore special care has to be provided for their preservation. Textile objects stored in museum collections need more protection since these objects, in most cases, have already suffered light degradation or other types of damage before being acquired by the museum and therefore more sensitive to environmental effects. Maintaining proper and stable relative humidity, temperature, and illumination; providing air filtration; dust, vibration and shock protection; establishing handling protocols and integrated pest management are crucial for the long-term preservation of these objects. Different factors have to be taken into account during storage, transport and exhibition. The various sources of damage intensify each other, and the effects are multiplied. Still, deterioration can be significantly reduced or minimalized by applying the proper environmental conditions, proper materials, techniques and equipment. In this paper, we will try to give a short overview of the most important damage factors and their effects on textiles that should be considered during storage and exhibition.

DAMAGE FACTORS OF DEGRADATION

The word “environment” refers to a series of conditions surrounding an object, the sum of “forces” created by nature and humans that can slow or accelerate the physical and chemical changes of the material. These changes are reflected both in the mechanical or chemical properties of the material and in the aesthetic appearance of the artefact. The destruction of textile fibers is caused by many damage factors that interact closely, in parallel and in competition with each other. They are divided into three major groups according to their appearance (not origin): biological, physical (mechanical) and chemical factors. Let me present these harmful factors from the visible to the microscopic size in order.

Biological factors

A major issue in collection management is establishing effective defense against insects and fungi, the two main types of pests. Since textiles are themselves organic materials and are also often combined with other organic materials like leather, paper, organic paints, animal glue, starch, different kinds of adhesives, etc., they are all exposed to almost all types of pests. It is impossible to list all of them, but textiles are most susceptible to moth- and mould infections (Figure 1).

There are approximately 160,000 species of moths, but only two species consider the textiles as a source of food: the case-making clothes moth (Tinea pellionella) and the webbing clothes moth (Tineola bisselliella). Both are about only 1 cm long and yellow or greyish. What causes specific damage is that they eat the object itself from mm to mm. All obvious signs of the infestation should be brushed or vacuumed away as soon as possible. Fumigation should be employed multiple times as fumes can only kill a live grub or a developed insect (the eggs are immune).

Figure 1: Moth infection on a textile upholstered armchair

Live mould can be recognised by the musty smell and the three-dimensional nature of the surface growth. Many types of mould can cause staining, weakening, or complete destruction of fibres. Moulds feed by digesting the substrate on which they grow. Cellulosic fibres such as cotton, linen, and rayon are particularly vulnerable, but proteins such as wool and silk can also be affected. Mould will even grow on synthetic fibres such as nylon and polyester if they are soiled or have finishes that provide food for the organism [1]. Spores of fungi can hide in the material for a very long time, even years, as long as the ambient humidity is not adequate for the spores to regenerate. Most fungi need at least 70% relative humidity to exert their vital activity. The optimum temperature for fungi is between 20 and 30 °C, but species developing at lower temperatures can also occur (Figure 2).

Nevertheless, mould is very harmful to humans as well: it can be allergens (substances that can cause an allergic reaction), irritants and, sometimes, toxic substances. Inhaling or touching mould spores may cause an allergic reaction, such as sneezing, a runny nose, red eyes and skin rash. Moulds can also cause asthma attacks. There are stringent protocols on how to disinfect and treat a mouldy object [2].

Figure 2: Mould infection on metal-thread decoration

To avoid these dangerous biological factors, the combination of the following main steps of pest management is carried out in museums:

(1) maintaining low temperature and heat treatment,
(2) carrying out pesticide treatment every year,
(3) adjusting insect and small animal (rodent) traps
(4) adhering the isolation protocol
(5) applying carbon dioxide, nitrogen treatment and gas fumigation (e.g. ethylene oxide) in case of need.

Physical factors

No matter how surprising, most injuries to textile objects (be they costumes or flat textiles) occur due to mishandling. The source of damage can be ourselves by accidental physical impacts or by vibrations caused by the rolling mechanism of a mobile shelving system, for example. Vibration is a common phenomenon in an urban environment. The sources can be diverse like traffic, subway or a construction site near the storage building or the museum.

The improper moving of the object or sometimes even a little moving causes mechanical stress. This tension in polymers creates so-called "activated bonds" in the artefact that can be broken even by low kinetic energy (e.g., light punch). "Activated bonds" require less photo or thermal energy to participate in various chemical degradation processes than non-activated ones. The radicals formed by the bond break immediately and undergo spontaneous chemical reactions that can cause their degradation [3]. This explains, for example, why previously patched fabric breaks down sooner than unsawn ones. It means in real life that the threads become extremely fragile, and the textile seems to be worn-out, shabby, threadbare, dingy, aged. In conservation, these physical lesions are detected thoroughly: condition assessment drawings are made of each part of the object on which the locations and the nature of the injuries are precisely marked. Figure 3 - the condition assessment of a right sleeve of a tailcoat from the end of the 18th century - clearly shows how fragile an artefact can be even if it is stored under proper conditions. Another striking aging - caused by mechanical stresses - can be observed on painted canvas, where the different layers (stretched canvas, primer, painted layer, lacquer layer, etc.) all behave differently due to changes in temperature and relative humidity. This results in splitting, warping of the layers, or scaling of the painted layers (Figure 4.)

Figure 3: The condition assessment of a right sleeve of a tailcoat from the end of the 18th century

The restoration of an artefact is intended to reinforce its structure and to maintain its condition. Nevertheless, it is crucial to physically protect an object even after conservation and not only ensure the optimal climate control. Foams, cloths, padding materials without harmful off-gassing can be used for effective protection. Objects are stored on open shelves but need to be covered or wrapped into VOC-free (Volatile Organic Compound) materials, like unbleached and undyed cotton or polyethylene film, bags, boxes. Tyvek (non-woven, soft, polyethylene-based material with antistatic coating), Hollytex (non-woven, acid-free wrapping material made of 100% polyester) or acid-free, unbuffered tissue paper are also good choices.

Figure 4: The bad condition of a painted canvas

Chemical factors

Whether from natural or synthetic sources, all fibres and dyes are organic, which in chemical terms means that the chemistry of carbon compounds is the branch of sciences with which the conservator is most concerned. The speed with which a compound breaks down depends on many factors, particularly stability in the presence of light, humidity, other gases in the atmosphere, heat, acids and alkalis. These factors exert an influence not only individually but also through complicated interactions [4].

The appropriate environmental conditions for the safe, long-term preservation of an artefact may differ from object to object depending on the environmental circumstances under which the object came from. The general guidelines for storage in Western collections are the following:

- Relative humidity: 45-55 %
- Temperature: 18-22 ^{0}C
- Light: 0 Lux in storage, max. 50 Lux in exhibition
- UV: 0 μW/lumen

Humidity

According to experts, the most versatile cause of the decomposition of organic materials is the relative humidity. The relative humidity (RH) is used to express the accurate humidity of the environment in relation to the saturation value achievable at the given temperature. The RH-induced changes in organic structures are classified into three major groups: 1) shape and size change, 2) chemical reaction occurrence and 3) biodegradation. In organic polymers, water acts as a “plasticizer”, thereby providing flexibility and elasticity to the material. If the RH is low, the textiles that have lost structural water will be stiff and brittle (Figure 5), while if the RH is too high, the fibres will swell, and harmful deformation may occur, e.g. dyed textiles will separate and crack. Furthermore, swollen materials are more permeable to degrading chemical reagents because vapor is good for atmospheric impurities. The growth of fungi and bacteria is favoured by humidity above 65%, while organic materials dry out below 40% RH.

Figure 5. The very brittle state of a damask fabric as a consequence of low humidity

What is most damaging for textiles is the fluctuation of RH. This alternation causes the material to swell and shrink constantly. The associated “stress” causes tension and deformation. At the same time, the sensitivity of the substance to chemical degradation also increases. It can therefore be concluded that the relative humidity of 45-55% is generally suitable for the conservation of organic materials, including a stable climate as sudden changes in humidity pose a greater risk than a relative humidity within a given but constant range even if it is not the optimum [3].

Providing the proper and stable humidity for textile objects is crucial for their long-term preservation. There are several ways for the maintenance of optimal RH levels. HVAC (Heating, ventilation and air conditioning) systems are used to provide an airflow that prevents indoor air stagnation, completed with air filtration, humidity and temperature control, using fresh air from outdoors. Using local sensors, the humidity can be controlled appropriately with this central system. Portable humidifiers can maintain a stable level of humidity in buildings without central humidity control. Built-in dehumidifiers can effectively reduce the moisture content of the air. Reduction of relative humidity is indispensable in humid storage buildings where the risk of mould formation is high.

Temperature

Thermodynamically, heat is defined as the energy that migrates from one place to another due to a temperature difference. Heat transfer can take place by heat flow, heat conduction or heat radiation. As an energy source, heat occurring in museum conditions can only cause the decomposition of very low energy bonds in organic compounds. However, it can trigger the disruption of activated bonds (activated bonds only need very little energy to break their bond). Heat also causes the movement of molecules in materials. The higher the temperature, the faster the molecule movement is. The rate of chemical reactions usually doubles with each temperature rise of 10°C. Many organic materials expand and soften at higher temperatures, thereby increasing their ability to absorb or bind chemical degradants. The solubility or dissociation of the substances involved in the reaction increases, facilitating the initiation and accelerating the course of chemical reactions.

As with relative humidity, temperature fluctuations are most dangerous. In general, the materials expand on heating and contract on cooling. Significant temperature fluctuations can cause stress in organic compounds and usually force them to rearrange physically. Ambient temperature determines the uptake and release of humidity of the organic compounds. An increase in temperature favours water uptake for some time, but the amount of moisture absorbed from the air generally decreases at high temperatures [3].

Overall, it can be stated that higher temperature accelerates degradation processes in the artefact and can cause alteration of original and restoration materials in the long run.

The HVAC system mentioned above and/or central heating system is used for regulating temperature in museum buildings in general. The location of the shelving system has to be carefully selected in storage because serious damage like shrinkage, cracking, flaking, or discoloration can occur if the objects are placed close to a heating unit. Portable air conditioners can help reduce the temperature in overheated areas, which is extremely important, especially in the summer season. The location of the devices has to be planned carefully because the cool airflow must not hit the objects directly.

Light

All forms of light are damaging to textiles. Photochemical reactions initiated by light energy can lead to the deterioration of the principally organic textile components. The damage to fabric by visible and invisible radiation is cumulative and irreversible. Although the wavelengths of the solar radiation start well below 200 nm, due to the presence of oxygen, nitrogen-dioxide, water vapor, and ozone occurring in the higher air layers, most rays below 286 nm do not penetrate the air. Although UV radiation between 286 nm and 400 nm, which reaches the surface, is in fact only 5% of the total radiation emitted by the sun, it is abundant enough to break down chemical bonds in organic materials [5]. Therefore, UV has to be eliminated. The shorter the wavelength, the more significant the damage. Photo-degradation of organic objects accelerates under wavelength 400 nm.

The UV and visible range of electromagnetic radiation can cause photolysis of organic materials (breaking of chemical bonds) and photochemical breakdown (chemical reactions using the energy of the radiation absorbed by the material). One of the most harmful degradation processes is photo-oxidation which results in the yellowing of the textile, changes of colours (Figure 6.) and the decrease in mechanical strength. These do not always appear on the fabric immediately because the process is an autocatalytic radical chain reaction that continues in the material even if the irradiation is stopped. Often, damage to organic material due to UV radiation or light only appears at the end of the exhibition or a few months afterward [3]. In addition, infrared radiation, which represents thermal energy, can cause thermal decomposition of the material and thermochemical reactions.

Figure 6: Discoloration of cotton fabric due to photo-oxidation

Light is the most harmful degradation factor for textiles because it can permanently degrade textile fibres. Therefore, light exposure should be kept to a minimum in storage areas. During work, handling, packing, general lighting shouldn't be more than 150 Lux. More intensive light sources are used for examination and research purposes but have to be restricted to a limited timeframe. Objects should be covered, kept in drawers or mobile shelving systems for protection against light.

Air pollutants

In addition to temperature, humidity and light, the concentration of air pollutants is another essential consideration. There are various sources of pollutants, namely:

(1) Ambient air pollutants from traffic and combustion, fine dust, human emissions (NO_X, SO_2, hydrocarbons, ozone, soot, dust and other aerosols);

(2) Emissions of surrounding exhibition installations and storage materials (furniture, shelves, flooring, packaging materials);

(3) Emissions of the objects themselves (volatile organic compounds (VOCs), in particular, acetic and formic acids, hydrogen sulfide, etc.).

All the contaminants mentioned above accelerate degradation significantly.

In particular contemporary objects made of synthetic fabric are very sensitive to air pollutants, as the surfaces of these objects are often electrostatically attracting dust and dirt. The attracted dust particles and the leaked and sticky plasticizers together form a layer of dirt that is very difficult to remove. Due to this type of pollution, many objects lose their aesthetic appearance and significance.

The most common VOCs are NOx, Ozone, PM (particulate matter), SO_2, H_2S, Carbon compounds, Chlorides, Ammonia. These pollutants are always present in lower or higher concentrations in an urban environment, but special weather conditions can cause their accumulation. Dust is also a kind of air pollutant concentration in the urban environment and can cause several indirect damages to objects. It is a fine, dry, airborne particle with a large specific surface, capable of adsorbing gases, solid or liquid particles or biological substances. Therefore, it can initialize damages, providing surface contact for these harmful materials.

As mentioned above, storage construction materials can also have harmful VOC off-gassing. Therefore we have to avoid using them in storage areas if possible. Chipboard, particleboard, MDF (medium-density fibreboard), plywood is often used for making cupboards, drawers or stands. They contain different synthetic glues like carbamide-formaldehyde, phenol-formaldehyde, melamine-formaldehyde resins. Natural woods like oak, beech, pine are off-gassing different acids, like acetic acid, formic acid, propionic and butyric acid. Safe shelving systems should be made of powder-coated steel or anodized aluminium.

The VOCs mentioned above have a wide range of direct and indirect harmful effects, which we have to eliminate from the environment of the objects. Air filtration can be effective by installing filter modules in HVAC systems, but mobile air purification units can complete the function of central systems or provide clean air in specific spaces. The damage caused by VOCs can be avoided by applying VCIs (Volatile Corrosion Inhibitor). The technology is based on materials that can vaporize or sublimate. The molecules condense on the object's surface, creating a barrier film that protects from acidic components, reactive corrosive gases, etc.

A CLOSE LOOK OF DEGRADED FIBERS

To demonstrate the combined effect of all the degradation factors mentioned above, a closer look at deteriorated silk threads could be a good example as silk is the most sensitive natural fibre to environmental effects. The thousand-times magnified shot of black silk fibres (Figure 7.) clearly shows the fibres' highly damaged and deteriorated state. The rapid degradation is due to its high level of tyrosine and tryptophan content. Tyrosine and tryptophan in the protein chain are easily oxidized by UV radiation. They are then converted to chromophore groups of yellow/brown colour while the peptide bonds of proteins are dissolved [3]. The level of degradation caused by electromagnetic radiation highly depends on the pH level. Due to the dissolution of the peptide bonds and the shortening of the chain-discharge, the fabric becomes stiff, brittle, rigid, fragile, and discoloured [3].

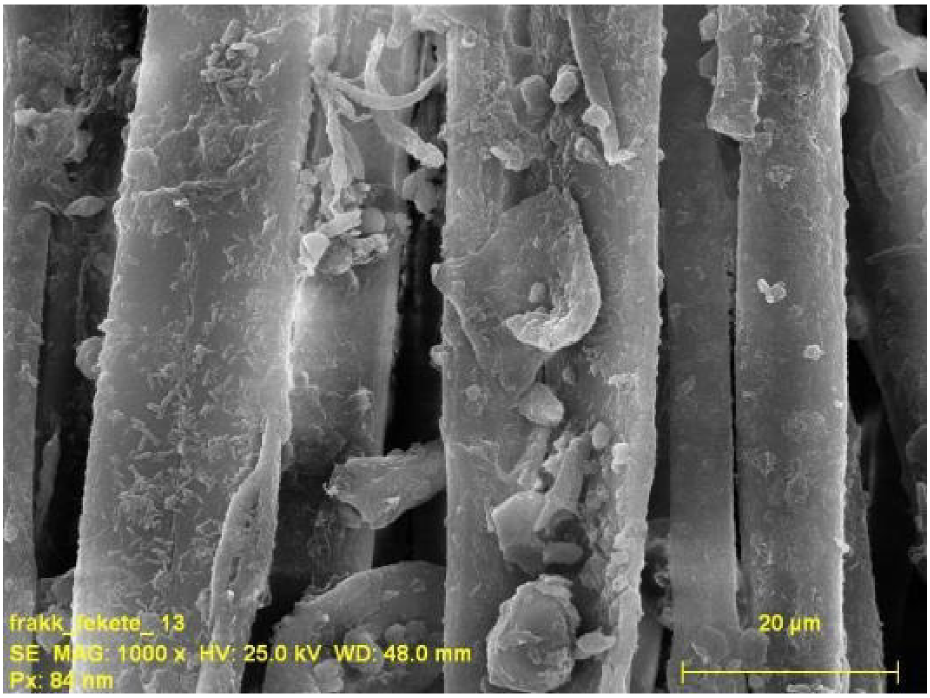

Fig.7: The deteriorated black silk fibres under thousand magnification using an electron-beam microscope

CONCLUSIONS

The physical and chemical properties of fibres, whether natural or synthetic, determine their behaviour in different environments. Their damage results from the physical, chemical and biological interactions between the objects and their surroundings. There is numerous scientific research to show the aging factors of natural fibres, but there is clear evidence of synthetic fibres' aging as well. The twentieth-century objects are often said to be "time bombs" waiting to explore in museum collections. It is becoming evident that these modern materials show signs of breakdown, sometimes dramatically and rapidly. Since they are only barely a hundred years old, there is only some practical experience on their behaviour, but not enough scientific data concerning their long-term future behaviour. However, there is a burning need in conservation to examine the deterioration factors of the different artificial threads to preserve them as much as possible for posterity. Future work will be based on the aging tests of artificial textiles to predict their future behaviour and determine their optimal environmental limits for preventive conservation.

Nevertheless, we must consider that keeping the environmental parameters (temperature, humidity, lighting, pest protection) at an optimal limit is not enough. There is no use to keep the temperature and relative humidity of a storage room on an optimal level if the condition of the building is poor (nitrous and mouldy walls, no insulation at the windows, no UV protection foil on the windows, etc.), there is no use to protect objects from pests if the textiles are stored on free shelves, stacked on top of each other without any protection/packaging materials.

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