# SIMULATION OF ACCELERATED AGEING OF POLYESTER FABRIC*

Tihana Dekanić[1], Ana Šaravanja[1]**, Julija Volmajer Valh[2], Tanja Pušić[1]

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[1]University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
[2]University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia

Human uncontrolled and careless habits and activities have disturbed the balance of the Earth's life cycle. Due to their effort to use natural resources as much as possible, humans have directly affected all the actors who live here, so that ecology has become an imperative today. Since the biggest polluters are factories in general, it can be stated that the textile industry is one of them. The increasing use of synthetic fibers in the production of textiles has led to some improvements in the form of mechanical, aesthetic and functional properties of the material. However, consumerism, the development of fast fashion, the rapid changes of fashion trends, irrational behavior and population growth have led to increased production of textiles based on synthetic fibers. Over the years, this has led to a slow accumulation of microfibers in the environment. Based on long-term test procedures under real conditions and with the aim of accelerating simulation, a standard polyester fabric is subjected to an artificial ageing process in this paper. By analyzing and characterizing the surface of the standard and the artificially aged fabric, and by instrumentally testing the tactile and mechanical properties, an attempt is made to gain insight into the behavior of the polyester fabric as a result of the applied modification. The results show that artificial ageing significantly affects the properties of polyester fabric, with a marked decrease in strength.

**Keywords:** polyester fabric, artificial ageing, surface structure, mechanical properties, touch feel

## Introduction

In order to make life easier for himself and others, man has affected the balance of the Earth's cycle through the uncontrolled exploitation of natural resources and habits. Due to the limited natural resources in nature and the large amount of raw materials needed to produce a small amount of products, the world is turning to the production of synthetic materials. A decade ago, synthetic polymers were a relatively cheap substitute for natural polymers. Nowadays, there is almost no product that contains a portion of synthetic polymers [1].

Textiles have been man's constant companion since ancient times. Originally, they served to protect against the cold and heat, while today they increasingly represent a fashion and aesthetic need [2]. The expansion of textile production, the development of fashion, major changes in trend, high birth rates and inappropriate behaviour have directly influenced the accelerated production of synthetic materials. Natural and synthetic materials and their blends allow people to feel comfortable and make life easier by their use [1].

The production of synthetic materials and the accumulation of waste lead to major ecological problems of environmental pollution [1,3]. Factories contribute most to this. With the development of technology for the production of synthetic fibres, they have become the predominant textile raw material and record a constant increase in production [4]. Polyester fibres, PES, are predominant in production [3]. They are characterised by good mechanical properties, fineness and brightness, chemical resistance, resistance to microorganisms and resistance to UV radiation, although degradation may occur with long-term exposure [5]. Due to the increasing use of PES fibres in textiles, the problem of microplastic release occurs, which has led to its accumulation in nature.

Natural and synthetic materials can degrade during their life cycle. The rate of degradation depends on the environment and temperature. Photodegradation has been shown to be the most important influencing factor [3]. The consequence of material ageing is a change in properties that, depending on the nature of the changes, extends or shortens the lifetime [6, 7].

The term *natural ageing* is used to describe changes in

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**Author address**: Ana Šaravanja, University of Zagreb, Faculty of Textile Technology, Zagreb, Croatia
E-mail: ana.saravanja@ttf.unizg.hr

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polymeric materials over time [3], under natural conditions. Since the products are exposed to natural conditions, i.e. atmospheric conditions for a long time, researchers are turning to accelerated artificial ageing under laboratory conditions. In order to evaluate the long-term properties of the product, it is possible to control the conditions during accelerated artificial ageing based on one or more environmental factors (e.g. precipitation, sunlight, day-night changes, etc.) corresponding to the exposure under natural conditions [8]. By combining the material exposure time, temperature and humidity change, and energy intensity during artificial ageing, it is possible to gain insight into the decomposition of the polymer material structure.

The aim of this paper is to investigate the effects of accelerated artificial ageing on polyester fabric under simulated UV irradiation. By analysing the properties of the fabric, an attempt is made to gain insight into the properties of the fabric. The effect of the simulation of accelerated artificial ageing on the material used will be determined based on the physical properties and the primary sense of touch and comfort.

## Material and methods

The properties of the standard polyester fabric used, CFT, Centre for Testmaterials BV, Netherlands are: mass per unit area 156.0 g/m$^2$, thickness 0.35 mm, yarn count (warp 30.4 tex and weft 31.9 tex), warp density 27.7 threads/cm, and weft density 20.0 threads/cm, white colour, plain weave.

Polyester fabric (PES_N) was subjected to the simulation of the process of artificial accelerated ageing in Xenotest 440, SDL Atlas device for 100 hours (100H) according to the standard HR EN ISO 4892-2+A1:2013 [9].

Microscopic observation of the samples of untreated and aged polyester fabric was performed using the digital principle with a Dino-Lite AM7013 microscope with 50x and 250x magnification.

The spectral characteristics were measured using a Spectraflash spectrophotometer SF 300, DataColor based on 5 individual measurements.

Fourier transform infrared spectroscopy using the attenuated total reflection (FTIR, Fourier Transform Infrared, Spectroscopy) in the wavelength range 4000-650 cm$^{-1}$ was used to characterise the samples.

A Fabric Touch Tester, SDL Atlas, model FTT M293, was used to obtain an overall assessment of the total active touch feel and comfort of the material. It is a device that simultaneously observes 13 parameters of fabric properties aligned to 4 modules: Bending module, Surface module, Thermal and Compression module. The most important touch properties - softness, softness, warmth, total active touch feel - are calculated using a computer system [10-12].

The breaking force and elongation of fabrics were measured using the strip method according to EN ISO 13934-1:2013 on the dynamometer Textechno H. Stein, Textechno Statigraph.

## Results and discussion

Figure 1 shows the microscopic images of the surface of the samples.

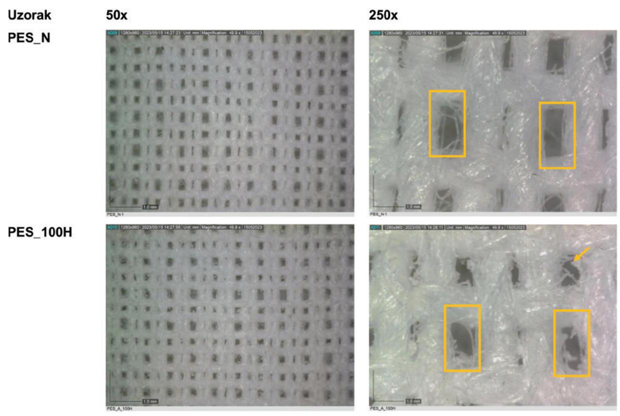
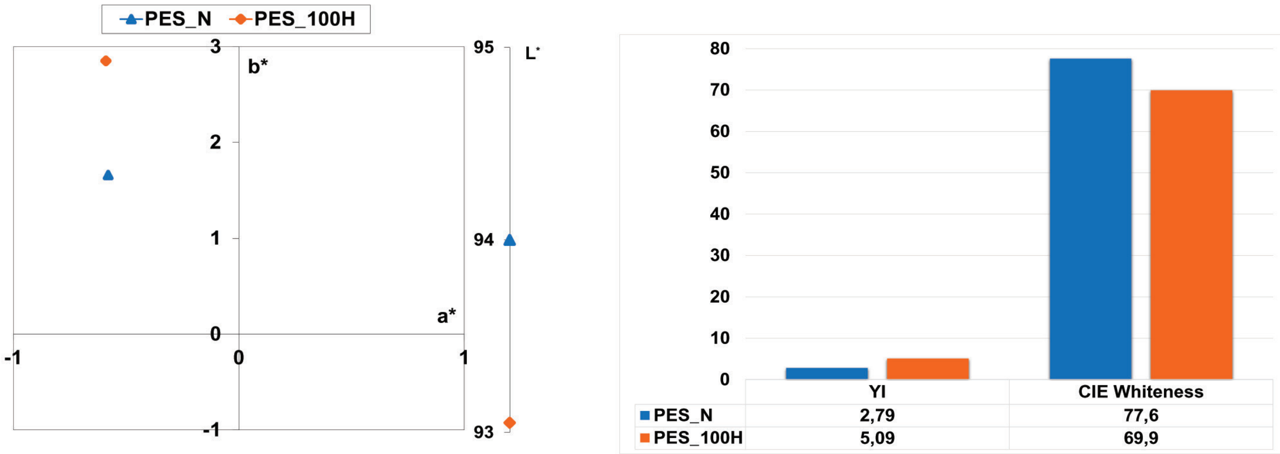



**Figure 1.** Microscopic images of untreated and artificially aged polyester fabric

Figure 1 shows changes in the pores of the aged polyester fabric. Small degradations of polyester fabric threads can be observed (arrow), which generally led to a decrease in pore size. Due to the heterogeneity of the textile material itself, it is not possible to clearly determine the size of the pores, as they are different (rectangle).

The spectral characteristics are shown in Figure 2. From the CIE L*a*b* parameters, the b* values were selected to represent the colourimetric results, since the most significant changes were observed in the b* parameter (yellowness).

After artificial ageing, the spectral characteristics of standard polyester fabrics change. The whiteness ($W_{CIE}$) of the aged fabric decreases ($W_{CIE}$ PES_N 77.6, $W_{CIE}$ PES_100H 69.9). Simultaneously yellowing (YI) increases from 2.79 to 5.09. In the CIEL*a*b* coordinate system, the values of the PES samples are in the second quadrant (-a*, +b*). The fabric aged under laboratory conditions shows a shift to the yellow hue by 1 unit (+b* 2.85), while the brightness decreases. The reason for this is that UV radiation acts on PES material since it causes it to turn yellow [13].




(a) (b)

**Figure 2.** Spectral characteristics of fabrics: (a). CIEL*a*b* coordinates, (b). yellowness index and degree of whiteness

FTIR spectra are one of the methods that have the ability to determine the changes that occur in the structure of the material after various modifications. Figure 3 shows the FTIR spectra of the samples.

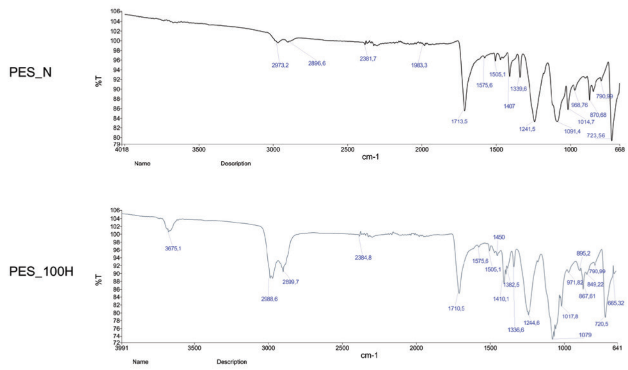



**Figure 3.** FTIR spectra of untreated and aged polyester fabric

The beginning of the band is represented by -OH functional groups detected in aged polyester fabric, peak 3675.1 cm$^{-1}$. Standard peaks for polyester can be seen on the FTIR bands: C=O 1713.5 cm$^{-1}$; 1407.0 cm$^{-1}$; 1241.5 cm$^{-1}$; 1091.4 cm$^{-1}$; 870.88 cm$^{-1}$. Peak 1500.1 cm$^{-1}$ is characteristic of the aromatic ring. The change was observed in the region around 2968.6 cm$^{-1}$, which corresponds to oxidation at the C-H bond [14-16]. For a more detailed analysis of the resulting changes, some additional analyses and combinations of exposure conditions will be necessary.

The parameters of the physical properties of untreated and aged fabric measured on the FTT device are shown in Table 1.

**Table 1.** FTT parameter values of standard and polyester fabric

| Samples | Bending | | Compression | | | | | Roughness | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | BARa | BARe | T | CW | CRR | CAR | RAR | SRAa | SRAe | SRWa | SRWe |
| PES_N | 79.88 | 0.18 | 0.33 | 242.64 | 0.62 | 1554.68 | 4490.61 | 36.37 | 0.00 | 1.60 | 0.00 |
| PES_100H | 205.25 | 0.00 | 0.36 | 293.47 | 0.67 | 1062.17 | 4697.77 | 67.21 | 0.00 | 1.91 | 0.00 |

The results after artificial ageing confirm changes that can also be perceived subjectively (visual roughness of the surface and tactile perception of the hand).

The bending parameter BAR (Bending Average Rigidity), more precisely BARa (Bending Average Rigidity of warp) PES_100H increases in relation to PES_N, while BARe (Bending Average Rigidity of weft), which is 0.18 at the beginning, decreases to 0.00. SRA (Surface Roughness Amplitude) and SRW (Surface Roughness Wavelength) increase in the warp direction during ageing, while they remain unchanged in the weft direction. The compression is evaluated by the following parameters: T (Thickness), CW (Compression Work), CRR (Compression Recovery Rate), CAR (Compression Average Rigidity) and RAR (Recovery Average Rigidity). The thickness of the aged PES fabric is negligible increase, as does the CRR (from 0.62 to 0.67). The compression average rigidity is decrease for 30%. Aged polyester fabric becomes stiffer after artificial ageing, which confirms the result of RAR. As mentioned above, the roughness results for FTT confirm the subjective observations on surface roughness and hand touch tactile perception (SRA and SRW).

The comfort rating of the material is expressed by 4 modules, which are shown in Table 2.

**Table 2.** Touch properties of polyester fabric before and after ageing

| Samples | Smoothness | Softness | Warmth | Total Active Touch Feel |
|---|---|---|---|---|
| **PES_N** | 5.0 | 5.0 | 1.0 | 5.0 |
| **PES_100H** | 5.0 | 2.0 | 3.0 | 4.0 |

The comfort rating of PES_100H decreases and the total active touch feel is 4.0, while PES_N has a rate of 5.0. The greatest decrease is observed in the softness parameter. In summary, a higher rating represents a higher comfort level of the material for a certain property.

In the context of this study, tensile properties are important for observing structural changes of the material.

Table 3 shows the results of breaking force ($F_b$) and elongation ($\varepsilon_b$) of untreated and aged polyester fabric based on three (3) individual measurements per sample in warp direction. Additionally, statistical indicators are shown through the average value, along with the standard deviation σ and the coefficient of variation (CV).

**Table 3.** The maximum force ($F_b$) and the elongation at maximum force ($\varepsilon_b$) for PES_N and PES_100H

| Samples | PES_N | | PES_A_100H | |
|---|---|---|---|---|
| | $F_b$ (N) | $\varepsilon_b$ (%) | $F_b$ (N) | $\varepsilon_b$ (%) |
| 1. | 930.66 | 45.42 | 516.60 | 49.33 |
| 2. | 890.44 | 47.20 | 538.08 | 49.71 |
| 3. | 917.81 | 47.47 | 523.44 | 48.24 |
| $x$ | 912.97 | 46.70 | 526.04 | 49.09 |
| σ | 20.54 | 1.11 | 10.97 | 0.76 |
| CV [%] | 2.25 | 2.39 | 2.09 | 1.55 |

According to the results from Table 3, the negative influence of artificial ageing on the physical properties of the material can be observed. Untreated polyester fabric has a breaking force of Fb 912.97 N, this value is considered to be a good integration of the polymer structure [17]. After the artificial ageing process, there are strong changes in the mechanical properties and a significant decrease in strength (from 917.97 N to 526.04 N). This can be interpreted by the increased stiffness of PES_100H caused by ageing, Table 1. At the same time, the elongation increased noticeably, namely by 5.11%.

## Conclusion

The effects of accelerated artificial ageing of the standard polyester fabric is monitored through morphological physico-chemical, mechanical and tactile properties. It can be seen that changes occur in the structure of the polyester chain (oxidation at the C-H bond). The degradation of the warp threads is visible after 100 hours of irradiation. Changes in spectral properties due to photolytic degradation were observed, as UV irradiation causes a decrease in whiteness with a simultaneous increase in the yellowing index. From the aspect of mechanical properties, sun exposure causes a high decrease in strength, which can be explained by the increased stiffness of the aged PES material. This also changes the comfort of the material.

The results show that the process of accelerated artificial ageing affects the changes of the analysed properties and the final evaluation of the comfort of the fabric, emphasising that no clear correlation can be established.

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**Nomenclature**

PES - Polyester fibres

PES_N – Standard polyester fabric

100H – Simulation of artificial ageing process for 100 hours of irradiation

PES_100H – Aged polyester fabric

FTIR - Fourier Transform Infrared, Spectroscopy

FTT – Fabric Touch Tester

CIE L*a*b* - CIELAB color space uses to measure objective color and calculate color differences. L* represents lightness from black to white on a scale of zero to 100, while a* and b* represent chromaticity with no specific numeric limits. Negative a* corresponds with green, positive a* corresponds with red, negative b* corresponds with blue and positive b* corresponds with yellow.

$W_{CIE}$ - The degree of whiteness according to CIE

YI – Yellowness Index

BAR - Bending Average Rigidity (a – warp; e- weft)

T – Thickness

CW - Compression Work
CRR – Compression Recovery Rate
CAR – Compression Average Rigidity
RAR – Recovery Average Rigidity
SRA – Surface Roughness Amplitude (a – warp; e- weft)
SRW – Surface Roughness Wavelength (a – warp; e- weft)
$F_b$ – Breaking force (maximum force recorded when a test specimen is taken to rupture during a tensile test under the specified conditions)
$\varepsilon_b$ - Elongation at maximum force

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**Izvod**

# SIMULACIJA UBRZANOG STARENJA POLIESTERSKE TKANINE

Tihana Dekanić[1], Ana Šaravanja[1], Julija Volmajer Valh[2], Tanja Pušić[1]

[1]Univerzitet u Zagrebu, Tekstilno-tehnološki fakultet, Zagreb, Hrvatska
[2]Univerzitet u Mariboru, Mašinski fakultet, Maribor, Slovenija

(ORIGINALNI NAUČNI RAD)
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Ljudske nekontrolisane i nemarne navike i aktivnosti narušile su ravnotežu životnog ciklusa Zemlje. Zbog nastojanja da što više koriste prirodne resurse, ljudi su direktno uticali na sve aktere koji ovde žive, tako da je ekologija danas postala imperativ. Pošto su najveći zagađivači fabrike uopšte, može se konstatovati da je tekstilna industrija jedna od njih. Sve veća upotreba sintetičkih vlakana u proizvodnji tekstila dovela je do određenih poboljšanja u vidu mehaničkih, estetskih i funkcionalnih svojstava materijala. Međutim, konzumerizam, razvoj brze mode, brze promene modnih trendova, neracionalno ponašanje i porast stanovništva doveli su do povećane proizvodnje tekstila na bazi sintetičkih vlakana. Tokom godina, to je dovelo do sporog nakupljanja mikrovlakana u okolini. Na osnovu dugotrajnih postupaka ispitivanja u realnim uslovima i sa ciljem ubrzanja simulacije, standardna poliesterska tkanina je u ovom radu podvrgnuta procesu veštačkog starenja. Analizom i karakterizacijom površine standardne i veštački ostarele tkanine, kao i instrumentalnim ispitivanjem taktilnih i mehaničkih svojstava, pokušava se steći uvid u ponašanje poliesterske tkanine kao rezultat primenjene modifikacije. Rezultati pokazuju da veštačko starenje značajno utiče na svojstva poliesterske tkanine, uz izrazito smanjenje čvrstoće.

**Ključne reči:** poliesterska tkanina, veštačko starenje, površinska struktura, mehanička svojstva, osećaj na dodir