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# Eco-Friendly Polyurethane Treatment to Enhance Mechanical Performance of Common and Technical Textiles

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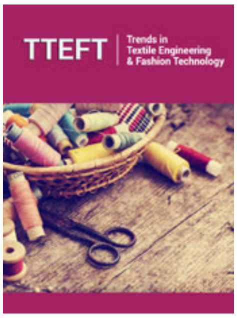

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## Abstract

The aim of this work was to summarize the effect of Waterborne Polyurethane (WPU) treatment on mechanical performance (i.e., puncture, tensile, tear, and abrasion resistance) of common and technical fabrics. Then, further improvements in mechanical properties of treated textiles, thanks to the addition of nanoparticles or crosslinking agent in WPU formulations, were discussed. Benefits in combining crosslinker and UV light stabilizers, to preserve the strength of treated textiles after UV accelerated aging, has been also reported.

## Introduction

Polyurethane (PU) has attracted scientific and industrial attention, thanks to the versatility of pristine constituents [1], that allowed an adaptable behaviour for a large variety of requirements and customized products (i.e., foams [2], composites [3], coatings and adhesives [4]). Particularly, this polymer is commonly used in advanced coatings technology thanks to improvement of quality, appearance, and lifespan of treated substrates. Due to severe environmental directives restricting the use of environmentally harmful products and the release of Volatile Organic Compounds (VOCs) in the surrounding, traditional solvent-based dispersions have been quickly replaced by Water-Based Dispersions (WPU) with low Volatile Organic Components (VOC) and co-solvents free [5]. Then, a wide range of additives have been introduced in formulations, as reinforcement for the PU matrix, or to enhance the final performance of WPU-based products, such as clay [6], silica (SiO ) nanoparticles[7], calcium carbonate ($CaCO_3$) [8], crosslinking agent [9], and UV light stabilizers (i.e., organic UV absorbers, hindered amine light stabilizers (Hals) or functional particles) [10]. In this work, the authors aimed to provide an overview about recent applications of waterborne polyurethane in the treatment of technical fabrics to enhance the mechanical performance of final textile products.

## Polyurethane (PU)

PU macromolecules are block copolymers composed of polar crystallizable units called Hard Segments (HS) and non-polar amorphous units called Soft Segments (SS) [11]. The hard segments are constituted by isocyanates (mostly aliphatic or aromatic) whereas the soft segments are made up of macrodiols (mostly polyester-based, polyether-based, polycarbonate-based). A schematization of chemical structure for polyurethane and corresponding pristine constituents is displayed in Figure 1.

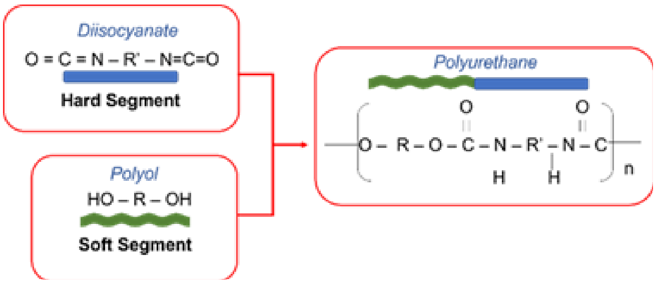

**Figure 1:** Chemical structure of polyurethane and pristine constituents.

## Waterborne Polyurethane (WPU)

Waterborne polyurethane is an aqueous colloidal system of PU particles, incorporating ionic (anionic, cationic, and zwitterions) and/or non-ionic (soft segment pendant group, such as polyethylene oxide) hydrophilic groups into the polymer backbone. This system is endowed with a high surface energy that represents the driving force for coalescence after water evaporation [12]. The stabilization of polyurethane, usually hydrophobic and insoluble in water, has been commonly accomplished though the addition of external or internal emulsifier in polymer backbone. When the internal emulsifier contains ionic center, the stabilization is achieved through the formation of electrical double layer. On the contrary, when the emulsifier includes non-ionic center, the stabilization is obtained through the steric hindrance phenomenon [13]. Depending on particles size, and appearance, different types of waterborne polyurethane can be distinguished [14]: transparent aqueous solutions when the particle sizes are lower than 1nm.

A. slightly turbid dispersions when the particle sizes are in the range between 1 and 100nm.

B. white and turbid emulsions when the particle sizes are greater than 100nm.

## Mechanical Performance of WPU-Treated Textiles

The effect of polyurethane treatment on final performance, in terms of tensile, tear, and abrasion resistance, of Polypropylene (PP)-based textiles, has been presented in the work by Patti et al. [15]. Four anionic waterborne polyurethane dispersions, different in chemistry, have been selected based on eco-friendly components:

A. A medium soft-aliphatic polyurethane binder polyether-based.

B. A medium-rigid aliphatic polyurethane binder polyester-based.

C. A high-rigid aliphatic polyurethane polycarbonate-based, and finally.

D. Polyurethane based on a perfluoropolyether backbone. These dispersions were applied to common woven technical fabrics through impregnation method. Experimental results proved that PU impregnation resulted to be a protective polymeric support, by preserving and making globally stronger fibers and filaments of basic textile. From the data, the starting PP textile possessed a breaking load approximately equal to 1kN, and an abrasion resistance equal to 25,000 cycles. Once impregnated, the developed specimens possessed a breaking load of about 1.4kN, and an abrasion resistance over than 100,000 cycles. The tear strength of neat PP was measured equal to 76N and remained approximately close to this value when the pristine fabric was impregnated.

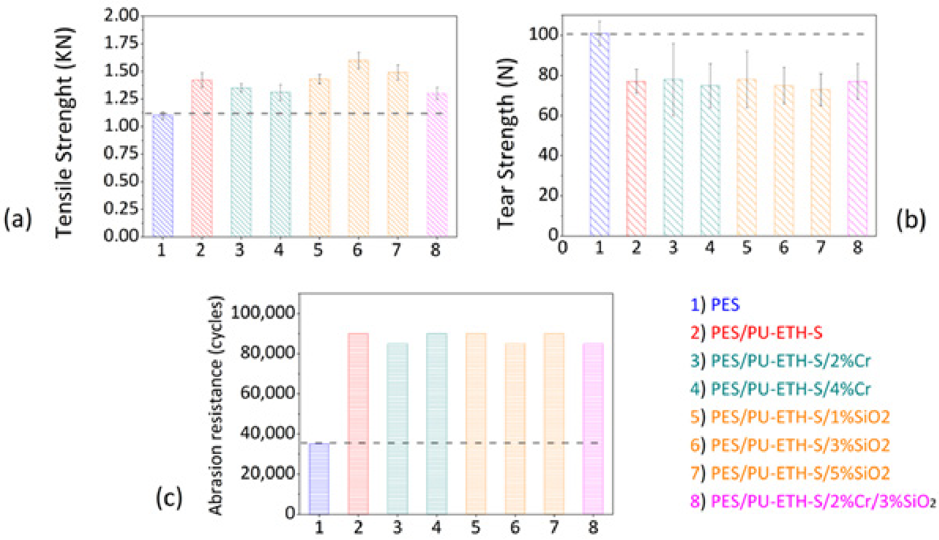

**Figure 2:** Tensile (a), tear (b), abrasion (c) resistance of WPUD impregnated PES-based fabrics. Data reproduced from [16].

Dip-coating technique was used to treat Polyester (PES)-based textiles with soft aliphatic polyether-based polyurethane, in form of an anionic waterborne dispersion (PU-ETH-S). Formulations containing crosslinker (Cr, content of 2 or 4% in wt.), silicon dioxide ($SiO_2$, content up to 5% in wt.), or a combination of both additives, have been adopted. As concerning tensile features, starting from a breaking load of about 1200N for the basic material (PES), the breaking load arrived up 1400N for PU-treated samples (PES-PU).

A slight increase (~13%) of the tensile strength in impregnated samples was attested, when aqueous polyurethane contained a percentage in $SiO_2$ content equal to 3wt.%. Abrasion resistance was attested equal to 35,000 cycles in pristine PES and was increased approximately 3 times when the textile was impregnated by WPU dispersion. On the contrary, in all the developed formulations, when the treated textiles were subjected to a tear stress, a strong decrement in the breaking load was measured with respect to untreated PES. Tensile, tear and abrasion resistance of polyester-based fabric, even treated with polyurethane, were summarized in Figure 2 [16]. Three different textiles, based on natural (100% linen and 100% cotton) or synthetic fibers (100% polypropylene) were impregnated with an aliphatic polyester-based polyurethane waterborne dispersion (35% in solid content). Crosslinker (up to 5% in wt.) and hydrophilic fumed nano-silica (up to 6% in wt.) have been added in aqueous polyurethane. The mechanical performance of treated textiles was measured in terms of puncture resistance through a dynamometer with different penetrators on crosshead: a rounded spike (diameter of 3mm) or pointed blade (width of 10mm). Results showed that, polyurethane impregnation determined an improvement of spike puncture resistance of treated fabrics, especially in the case of synthetic constituents (~20%), and a decrease of blade puncture resistance, in particular for natural fibers [17].

Impregnating formulations, made from commercially available WPU at high concentration in solid (~60%), and content of hydrophilic silica nanoparticles higher than 6wt.% (up to 25% in wt.), were used as treatment for PP-based fabric in [18]. The introduction of other additives in WPU, such as hydrophobic silica nanoparticles or crosslinking agent, has been also tested. Developed specimens have been characterized through quasi-static perforation tests performed in longitudinal direction through a dynamometer machine equipped with a spherical spike and pointed blade, or the transversal action of rotating circular blade running on specimens. The best fabric features (blade strength increase of 63% and puncture strength increase of 71% compared to the neat material) were obtained by combining hydrophilic nano $SiO_2$ and crosslinker into the polyurethane. Finally, the effect of waterborne polyurethane dispersion applied to a polyester-based fabric, through the impregnation, on the mechanical strength of the pristine material, before and after UV weathering was analysed in [19]. From a comparison between performance of treated (puncture load of 192N) and untreated (puncture load of 136N) fabrics, it was shown that polyurethane impregnation increased the puncture strength of +27.5%. Following the UV weathering, these benefits completely vanished, and a loss of perforation load (that achieved the value of 115N) amounted to -48.5% . To improve the durability of treated materials, the addition of organic UV absorbers, hindered amine light stabilizers (Hals) or functional particles (zinc oxide, ZnO), in content up to 7 wt.%, into the coating formulations, has been studied. The optimal solution was identified in impregnating formulations containing both crosslinker and UV light stabilizer. In this case, the perforating strength of corresponding treated textiles (149N) was found higher compared to the neat textile (136N) also after a period of UV accelerating aging in dry air at 35 °C for 8 days.

## Conclusion

Commercial textiles were treated with waterborne polyurethanes, and characterized in terms of tensile, tear, abrasion, and puncture resistance. Experimental results highlighted different benefits coming from polyurethane application to the textile weave of neat fabric. In all WPU-treated samples, an increase in breaking load, abrasion resistance, puncture strength was always detected with respect to untreated specimens. As concerning the tear strength and blade puncture strength, depending on material constituting the textiles fibers, the resistance appears to even be decreased. Then, following UV aging, samples lost some of the gained properties attributed to polyurethane polymeric treatment. In this regard, the addition of UV light stabilizers (UV absorber (HPT), HALs, and nanoparticles), in combination with crosslinking agent into WPU formulation, were found to be useful in increasing the durability of PU treatment against the UV weathering.

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