EFFECTS OF ULTRAVIOLET AGING ON THE MECHANICAL PROPERTIES OF HEMP FIBERS

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Introduction

In the recent years, natural fiber-reinforced composites are widely used in different applications due to their good behaviors, such as lightweight, high specific strength and degradability. However, the plant fibers are sensitive to weathering, comparing to artificial fibers. Hemp fibers exposed to ultraviolet (UV) radiation can affect their appearances as well as mechanical properties [1], which limits their performances. In addition, hemp fibers can also be affected by the presence of moisture due to their hydrophilic behavior. Under condition that water completely penetrates into hemp cell walls, the expansion of cell walls will make the light more accessible and provide more positions for further degradation [2]. The combination of UV radiation and moisture can degrade hemp fibers more effectively than just make the exposure to UV radiation. The effect of water accelerates the oxidation reaction and the water spray also wash the degraded layers away to leave new layers exposed to UV radiation.

The objective of this study is to investigate the influence of UV on the mechanical properties of hemp fibers after an accelerated aging with UV radiation coupled with the water spray.

Experimental procedure

Materials

Hemp fibers applied in this work were supplied with fiber bundles by our industrial partner.

Micro-tensile tests

Individual hemp fibers were separated with caution from the fiber bundles and they were all fixed on the slotted pieces of thick paper with 60 mm×10 mm [3-4], in which two droplets of glue were applied in Fig.1**.** All the prepared samples were stocked at 21±2 °C and 50±5% relative humidity (RH). The tensile tests were performed on a horizontal micro-tensile machine of capacity 100 N with a minimum measurement accuracy of 0.05 N. A displacement speed 12 μm/min was imposed to all the tests and the results were well recorded by a computer program.

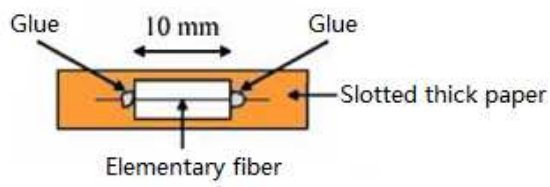

Fig.1 Illustration of individual testing sample.

Weathering

Two different types of samples were placed in an aging machine: one type is a bundle of fibers to measure their weight variations and the other type is just the prepared individual fibers. The exposure was a 2-h cycle consisting of a duration of 108 min of UV radiation at 38±2°C and 50±5% RH, and a subsequent duration of 12 min with simultaneous water spray and UV radiation. Xenon-arc-type light intensity is 60±2W/m² with a wavelength between 300 and 400 nm. A number of hemp fibers samples were taken from the aging machine every week within 4 weeks.

Results and discussion

Tensile property analysis

All the prepared samples become white after 1 week's exposure. Tab.1 provides the mechanical properties of aged hemp fibers from the micro-

Tab.1 Mechanical properties of aged hemp fibers

Fiber samples	Young's modulus (GPa)	Yield stress (MPa)	Fracture strain (%)
No aging	17.42±4.15	253.62±33.23	1.77±0.51
UV aging 1 week	9.32±1.59	140.51±34.62	1.74±0.39
UV aging 2 weeks	8.77±1.77	117.84±28.52	1.73±0.55
UV aging 3 weeks	4.56±1.19	99.85±23.68	1.52±0.61
UV aging 4 weeks	2.21±0.88	71.27±18.50	1.51±0.62

tensile tests after 1, 2, 3 and 4 weeks' exposure respectively. The tensile modulus, yield strength and fracture strain clearly decrease with the UV aging progression. After 1 week's exposure, the Young's modulus and yield stress just remain about half of their initial values. After 4 weeks' aging, hemp fibers nearly lose their 87% initial modulus and 72% initial strength. The fracture strain owns a gently downward trend with the UV aging time, contrary to the results in RH aging reported in our previous study [5].

Aging mechanism analysis

UV exposure mainly causes two types of degradations in the mechanical properties of hemp fibers:

1. Photolysis - chemical reaction in which the chemical bonds are broken by photons. The C-C and C-O bond energy E in cellulose molecules are about $3.35\times10^{2}\sim3.77\times10^{2}$ kJ/mol. The energy produced by UV wavelength λ of 340nm directly causes the cellulose degradation, as following:

$$E=h\upsilon=\frac{hc}{\lambda}=\frac{120.000}{\lambda}(\text{E in kJ/mol},\lambda \text{ in nm}) \quad (1)$$

2. Photosensitization – photochemistry reaction involves transforming light into other forms of energy. The molecules activated by the photon absorption transfer the energy to the oxygen in air. Ozone and hydrogen peroxide can promote oxidative degradation of cellulose by their strong oxidizing properties.

$$O_2 \xrightarrow{energy} 2O^* \quad (2)$$

$$O^*+O_2 \xrightarrow{energy} O_3 \quad (3)$$

$$O^*+H_2O \xrightarrow{energy} H_2O_2 \quad (4)$$

The polymerization degree of cellulose decreases when the hydroxyl is oxidized that weaken the fiber's strength. The oxidation degradation also causes the breakdown of macromolecular chain. By the oxidation of cellulose, carbonyl groups become the C_2 and C_3 forms, respectively. Owing to the formations of carbonyl groups on the glucose units, the molecular chain generates β-alkoxy carbonyl structure. When α-carbon of a strong electron withdrawing group is connected by hydrogen atom, the ether bond β-carbon becomes unsteady and easily broken, as β-cleavage in Fig.2. This reaction can also occur in other parts of the macromolecules of hemp fibers. Fig.3 provides the various oxidized cellulose structures, the parts surrounded by the dotted line indicate β-alkoxy elimination reaction caused by the formation of carbonyl, which leads to the glycoside bond fracture.

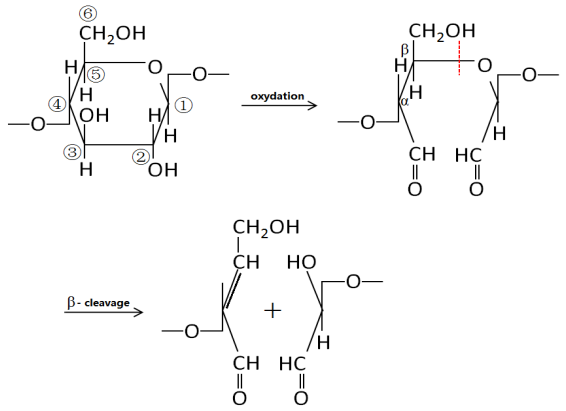

Fig.2 Cellulose oxidation and one type of β-cleavage.

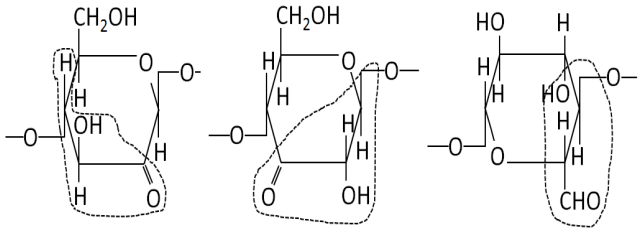

Fig.3 Other types of β-cleavage in oxidized cellulose.

Conclusions

The mechanical properties of hemp fibers generally decrease with the UV aging process. Photo-degradation and oxidative degradation cause the chain scissions of cellulose. Water can't only accelerate the oxidation reaction, but also make cell walls swelling to facilitate light penetrating into hemp fibers. Water spray also washes the oxide layers away that keeps hemp fiber white in the UV aging process.

References

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