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A NEW FIBRE: POLYLACTIC ACID (PLA)

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Abstract:
Poly(lactic acid) (PLA) is a linear aliphatic thermoplastic polyester derived from 100% renewable sources such as corn, and the polymer is compostable. The biodegradability makes it highly attractive for biological and medical applications.
It has a number of characteristics that are similar to many other thermoplastic fibres, such as controlled crimp, smooth surface and low moisture regain. The tensile properties of PLA fibre are very different from those of high tenacity polyester and more akin to wool with a high fibre extension when stressed and relatively low final tenacity. Similar to PET, PLA is dyed with disperse dyes. PLA fibres can be used for apparel, homeware, nonwovens, and also for medical applications.
Advantageous fibre properties and sustainability make PLA a very promising new material. Hopefully, in the not too distance future PLA fibres will be available in Hungary. Textile community should be prepared to process this new pleasant fibre.

Keywords: polylactic acid fibre, polyester fibre, biodegradation, sustainability

1 INTRODUCTION [1]

In a world that is becoming increasingly sensitive to the need to protect our environment, the ability to manufacture products from sustainable resources and which are fully compostable at the end of their useful life, is an exciting and attractive proposition. Poly(lactic acid) (PLA) is a linear aliphatic thermoplastic polyester derived from 100% renewable sources such as corn, and the polymer is biodegradable.
NatureWorks LLC (USA) has developed large-scale operations for the economic production of PLA polymer (Ingeo™) used for packaging and fibre applications. PLA fibre is a completely new generic class of synthetic fibres.

Paper will review the sustainability of PLA production, the chemistry of PLA and some properties of PLA fibres.

2 SUSTAINABILITY OF PLA PRODUCTION [1]

Conventional synthetic polymers rely on reserves of oil and gas for their monomer source and energy to manufacture. These reserves of fossil fuel take millions of years to regenerate and are a declining resource. In contrast, the monomer used to manufacture poly(lactic acid) is obtained from annually renewable crops. Energy from the sun promotes photosynthesis within the plant cells; carbon dioxide and water from the atmosphere are converted into starch. This starch is readily extracted from plant

matter and converted to a fermentable sugar (e.g. glucose) by enzymatic hydrolysis. The carbon and other elements in these natural sugars are then converted to lactic acid through fermentation.
Composting is a method of waste disposal that allows organic materials to be recycled into a product that can be used as a valuable soil amendment. The primary mechanism of degradation of PLA is hydrolysis, catalyzed by temperature, followed by bacterial attack on the fragmented residues. In composting, the moisture and the heat in the compost pile attacks the PLA polymer chains and splits them apart, creating smaller polymer fragments, and finally, lactic acid. Microorganisms, found in active compost piles, consume the smaller polymer fragments and lactic acid as energy source. Since lactic acid is widely found in nature, a large number of naturally occurring organisms metabolize lactic acid.

The life cycle of PLA is presented on Fig. 1.

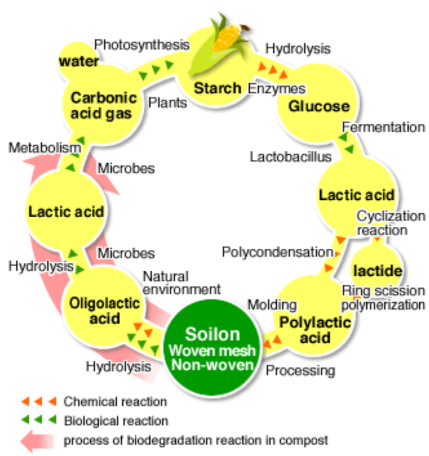

Figure 1: Lyfe cycle of polylactic acid [2]

3 CHEMISTRY

Lactic acid (2-hydroxypropanoic acid), also known as milk acid plays role in several biochemical processes. Lactic acid is chiral (exists as ‘mirror images’) and has two optical isomers. One is known as L-(+)-lactic acid or (*S*)-lactic acid and the other, its mirror image, is D-(−)-lactic acid or (*R*)-lactic acid. L-(+)-Lactic acid is the biologically important isomer (Fig 2).

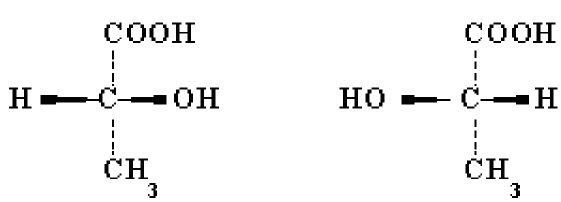

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Figure 2: The stereoisomers of lactic acid

Polycondensation of lactic acid involves the removal of water under high vacuum and temperature. High molecular weight polymer (Fig. 3) is produced using tin catalyst.

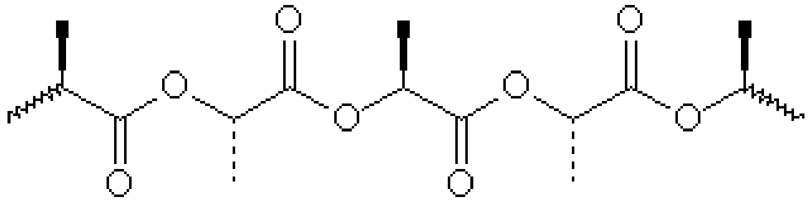

Figure 3: Polylactic acid

4 PLA FIBRE

PLA fibre has a number of characteristics that are similar to many other thermoplastic fibres, such as controlled crimp, smooth surface and low moisture regain. Some properties (thermal properties, tensile properties, tenacity, moisture regain and transport, flammability, UV-, chemical and biological resistance) are presented in details.

4.1 Thermal properties

PLA is a stiff polymer at room temperature. The glass transition temperature (Tg) is typically between 55–65°C. The melting temperature (Tm) of PLA containing either the L- or D-isomeric form alone, is between 160–170°C. The properties of PLA can be modified by adjusting the ratio and the distribution of the D- and L-isomers in the polymer chain, and melting points as low as 130°C and as high as 220°C have been obtained.

4.2 Tensile properties, tenacity

The tensile properties of PLA fiber as used in staple form for textile processing are shown in Fig. 4. They are very different from those of high tenacity polyester and more akin to wool with a high fiber extension when stressed and relatively low final tenacity. The initial modulus (at 2% extension) is very similar to many other textile fibers, but the yield point is very marked, the fibers (and spun yarns) stretching very easily once past this point. A consequence, however, of the high elongation is that the work of rupture is relatively high giving yarns and fabrics an acceptable performance in commercial use. Elastic recovery is affected by the yield point and is particularly good at low strains. At 2% strain, the recovery is 99.2% +/– 0.75%, and 92.6% +/– 1.60% at 5% strain, higher than for most other fibers.

The tenacity at break (32–36 cN tex–1) is higher than for natural fibers although, of course, it can be varied according to the degree of drawing that is applied to the undrawn yarn. It is relatively unaffected by changes in humidity at ambient temperature, though as with other manufactured fibers there is a small but measurable increase in elongation. As the temperature is increased the tenacity does reduce quite quickly with a concomitant increase in fiber extension, a feature commonly found in synthetic fibers.

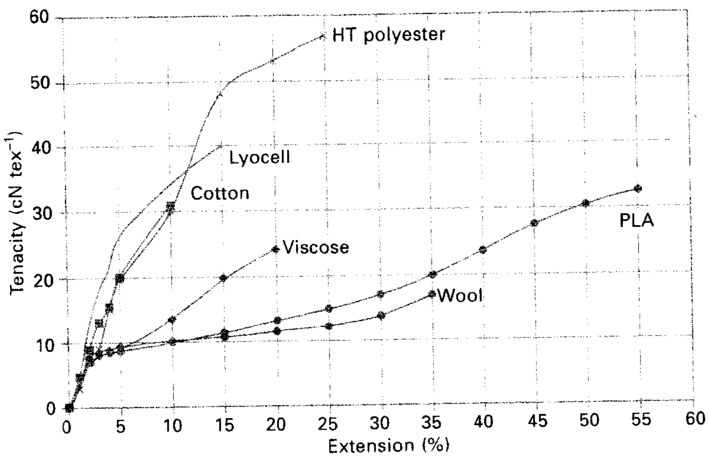

Figure 4: Tenacity-extension curves for PLA and other common textile fibers (20 °C, 65% RH).

4.3 Moisture regain and transport

At 0.4–0.6%, PLA has extremely low moisture regain, much lower than natural fibers and slightly higher than polyester. PLA shows excellent wicking ability. This property and the additional properties of fast water spreading and rapid drying capability give the fiber a very positive inherent moisture management characteristic.

4.4 Flammability

Although PLA is not a non-flammable polymer, the fiber has good self-extinguishing characteristics; it burns for two minutes after a flame is removed, and burns with a white and a low smoke generation. PLA also has a higher LOI (limiting oxygen index) compared to most other fibers, meaning that it is more difficult to ignite as it requires greater oxygen level.

4.5 UV, chemical and biological resistance

Unlike other synthetic fibers, PLA does not absorb light in the visible region of the spectrum; this leads to very low strength loss compared to petroleum-based fibers when exposed to ultraviolet light. As PLA is a linear aliphatic fiber, its resistance to hydrolysis is therefore relatively poor. This feature means that care must be taken in dyeing and finishing of the fiber. Although PLA fibers are not inherently ‘antimicrobial’ without suitable after-finish treatment, they do not provide a microbial food source. In addition, testing by Odor Science and Engineering showed that PLA fiber-based fabrics outperformed PET-based fabrics for low odor retention.

5 APPLICATION

The ease of melt processing, coupled with the unique property spectrum and renewable resource origin, has led to PLA fibers finding increasing acceptance across a variety of commercial sectors (apparel, homeware, nonwovens).

Similar to PET, PLA is dyed with disperse dyes. However, dye selection is most important, as the individual dye behavior is quite different from dyeing on PET. In general terms, dyes show their maximum absorption at a shorter wavelength than on PET and tend to look brighter. With the introduction of PLA into apparel, developments and commercial adoptions have included fabrics made from 100% PLA as well as in blend with other fibers. The main blends are either with cellulosic fibers (cotton, lyocell) or wool. Apart from any aesthetic or performance benefits, such blends also have the feature of being biodegradable compared to their PET counterparts. The wet processing of cellulosic blends need to be adapted to recognize the sensitivity of PLA to alkali treatments. This causes some limitations, as bleaching and dyeing systems for cellulosic fibers generally use alkaline processes. However, the potential significance of this blend has been recognized, and methods are available for all stages of wet processing. These include the use of neutral bleaching systems based on TAED (tetraacetylethylenediamine), and direct dyes, as well as the more conventional alkaline bleaches and selected reactive dyeing systems.

6 DISCUSSION

Advantageous fibre properties and sustainability make PLA a very promising new material. Hopefully, in the not too distance future PLA fibres will be available in Hungary. Textile community should be prepared to process this new pleasant fibre.

7 REFERENCES

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[2] Yamanaka (web 2010)

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