Sustainably dyed and functionalized biobased poly (lactic acid) fibers for textile applications

Impact Chapter

The social and economic impact that can be generated by the current research work is discussed in this chapter. The application of multifunctional colorants for improving the properties of PLA to make more sustainable textile products is focused on this dissertation. The textile industry is heavily dependent on fossil-based polymers, especially PET with a market of about 48 million tons and to battle against climate change and CO_2 production, it is aiming to shift towards more sustainable polymers such as PLA [1]. It is a biobased material made from sustainable feedstock and the production of 1 tons of PLA consumes 42 GJ of energy and releases 1.3 tons of CO_2, ~40% less than PET [2]. Apart from the polymer used, the textile industry depends a lot on colorants also since appearance influences the buying decision. The global market of colorants is huge and growing and is expected to reach €98 Billion by 2030 [3]. Vast majority of these colorants are fossil-based but the market is also shifting towards more biobased colorants to make the industry more sustainable. However, due to low yield, thermal stability of these biobased colorants, it is still a bit challenging.

Even though a lot of focus has been put on shifting towards more sustainable materials, development of corresponding sustainable processing is still lacking. For ex., exhaust dyeing is the most common process used to dye conventional textiles and during this process, the toxic effluents released leads to contamination of water bodies and is also not the best choice for PLA because of its low heat stability and hydrolytic degradation [4,5]. Although the Covid-19 outburst led to significant improvement in the filter (nonwoven) market, it did not seem to accelerate the use of sustainable materials and methods to produce these filters [6]. Melt electrospinning is an upcoming and a potentially sustainable way to produce such materials but the required functionalities and fiber diameters are challenging to reach with this process.

In this dissertation, we have proposed the use of multifunctional colorants to address these shortcomings. Here we proposed the use of sustainable dope dyeing to dye PLA filaments to avoid the degradation that happens during exhaust dyeing. This not only gives filaments with better properties but also reduces waste production considerably since in exhaust dyeing, upto 20% of the dye used can stay behind in the dye bath and when these effluents are thrown away, it causes water pollution [7]. Melt electrospinning, although promising, has been limited mostly to lab scale until now. In this research, we proposed the use of colorants as multifunctional additives for pilot-scale melt electrospinning of PLA and produced antibacterial nonwoven fiber webs. The trials in this dissertation were carried out in pilot scale and therefore, the findings reported especially in chapter 2 and chapter 5, are very promising for industrial scale up and valorization.

The first part of the thesis dealt with dope dyeing of PLA for conventional textile applications. One of the targeted applications for the developed product are the apparels. After discussion with industrial partners, we observed that the properties of the yarn developed in this dissertation are comparable to the properties of the ones used for sock manufacture in the market. The UV fastness obtained from the biobased and potential biobased colorants in this dissertation are comparable to fossil-based colorants. This gives potential for the manufacture of fully biobased socks that can be potentially sustainable. Furthermore, the superior wicking property of PLA improves comfort of the sock [8]. Similar to sock, the yarn developed here can potential be used for other apparel applications such as sports T-shirts. A Belgian company called Noosa is developing this technology and are working on developing PLA based apparels. Starsock, a sock manufacturer in the Netherlands, are also interested in developing sustainable PLA based socks. Currently, as an extension of the thesis, work is being carried out under the framework of Biotexfuture project "Biobase" in Germany with several industrial partners to explore the possibility of using biopolymers for several textile applications.

Apart from apparels, the European flooring industry is looking for sustainable alternatives. The bulk continuous filament or commonly known as carpet yarn is typically dope dyed. Therefore, the results of this dissertation can be very interesting for the carpet industry. The Dutch and Belgian companies such as Low & Bonar, TWE Meulebeke BCBA can make use of the results of this dissertation to make potentially sustainable carpets.

The second part of the thesis focused on developing fiberwebs with low diameters using pilot-scale melt electrospinning for potential filtration applications. Antimicrobial filters have gained a lot of importance since 2020 and the market was estimated to reach €32 billion in 2022 but fossil-based PP and polyethylenesulfone are the major players here [9]. Fibers with low diameter in the low-micro and nanoranges are necessary to function as effective filters to filter viruses, bacteria, also fine dust [10]. Inorganic additives such as silver are generally used to impart anti-microbial functionalities on these filters and fossil-based polymers are used here making this industry unsustainable. The approach proposed in this dissertation for the use of multifunctional colorants to reduce the diameter of PLA fibers in meltelectrospinning and to impart anti-microbial functionality at the same time can be very interesting for filtration applications. These results can be made use of develop more sustainable HEPA filters and air filters for airplanes and hospitals.

The antibacterial PLA fiber web developed in this dissertation can be a sustainable alternative for the wound dressing market. Apart from being antibacterial, colorants such as curcumin and alizarin used in the study are pH responsive. The pH of a wound changes through the healing process and because of the anti-bacterial properties and the pH responsive nature, the fiber webs developed here can support the healing process and function as smart wound dressing to show the status of the wound healing. This could be hugely beneficial for the patient with the wound.

In addition to textile applications, the antibacterial nature of the potentially biobased colorants used in this work can also be beneficial for food packaging. The antibacterial PLA composite developed in this dissertation can potentially be used to create sustainable anti-bacterial packaging material. The slow crystallization rate of PLA can be a hindrance to achieve high production rates during injection molding of products such as cutleries, plates. Here we demonstrated the performance of colorants as nucleating agents for PLA. The developed composite can be used in injection molding to improve the production rates. With nucleating agents, the crystallization process occurring during molding can be accelerated and thus the production time can be reduced.

Although some questions, such as washing stability of the colorants, filtration efficiency of the fiber webs, need to be investigated, this dissertation showed the potential of multifunctional colorants to improve the properties of PLA. Production of PLA is observed to emit lower amounts of CO_2 compared to PET. Apart from this, the processing temperatures of PLA are lower than that of PET, which could also lead to lower energy consumptions on the long run. Furthermore, the wicking behavior of PLA is better than PET giving consumers' textile materials that can be more comfortable to wear. The reduction of effluents by the use of dope dyeing reduces water pollution. Mixing colorants and PLA can also lead to production of smart wound dressing materials and anti-bacterial filters. By exploring these benefits, the results of this dissertation can be used to make the world potentially more sustainable through development of functional PLA based textiles.

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