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A sample work on green manufacturing in textile industry

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ABSTRACT

It has been seen that the approaches related to green-manufacturing have significant role in textile industries upon improvement of awareness on environmentally friendly point of view.

Environmental impacts of the material should be taken into consideration for improving new textile structures. Materials should be composed of environmentally friendly raw material and the harmful emissions of whole production processes should be limited, while the material should be easily disposable with no detrimental effects on the environment after use.

The aim of this study is to develop textile structures which have sustainable, environmentally friendly and functional characteristics. Antibacterial knitted fabrics have been improved in this study. Raw materials were selected among environmentally friendly new generation fibers. PLA (Polylactic acid), lyocell and chitosan fibers were mixed, the single jersey knitted fabric composed of 80% PLA 15% Lyocell 5% Chitosan having thickness of 30/1 were produced. Production processes which minimize harmful emissions to the environment were used. Antibacterial efficiency of the designed fabric was tested according to AATCC100. In addition, biodegradation of the improved knitted fabric was tested in soil burial test under standardized laboratory conditions for a defined test period of 4, 12 and 24 weeks. After soil burial test, the ecotoxicological assessment of soil was performed with plants growth test.

1. Introduction

Textile industry is one of the most complicated industries among the manufacturing industries which gathers the agricultural, chemical fiber, textile, apparel, retail, service and waste management sectors (Beton et al., 2006).

Sustainable development involves economic development, social development and environmental protection (UN General Assembly, 2005). The unfavorable impact of chemicals is one of the environmental concerns regarding sustainable development in addition to greenhouse gas emissions, depletion of water and resources, and acidification etc. (Ross, 2015).

Awareness on the health and environmental impact caused by the use of hazardous chemicals in the textile industry is increasing. In order to assess and reduce the exposure of people and nature to detrimental chemicals, practical tools are needed (Beton et al., 2006; Dahllöf, 2003; World Business Council for Sustainable Development, 2012).

Life cycle assessment (LCA) is a tool that evaluates the environmental effects associated with the full life cycle of products or production systems (Beton et al., 2006; Dahllöf, 2003).

The life cycle impacts of the textile garments are analyzed in four phases. These are production and processing, distribution, use and end-of-life.

The production and processing phase is the most efficient phase regarding the use of natural fibers due to the fact that land and fertilizers are required during cultivation period which impacts eutrophication, agricultural land occupation and natural land transformation. Water or energy consumption and characteristics of raw materials have significant importance in production and processing phases alongside wastewater generation and its contamination (Beton et al., 2006; Cleaner Production Institute, 2009).

Impacts of energy and water consumption which induce fossil fuel depletion, climate change, ozone depletion, photochemical oxidant formation and etc. are at the high level along with the value chain of textile products. The use phase includes washing, tumble drying and ironing. The detergent and the energy used during the washing process have provided significant contribution particularly to the toxicity indicators related to human beings and water ecosystems. Therefore, potential consequences of the effect on freshwater and marine toxicity occur on ecosystem diversity. On the other hand, the use phase is more important than the production and processing phase because of high water

Abbreviations: PLA, Polylactic acid; LCA, Life cycle assessment; LCI, life cycle inventory; LCIA, life cycle impact assessment; PES, Polyester; *S. aureus*, *Staphylococcus aureus*; *S. epidermidis*, *Staphylococcus epidermidis*; MRSA, Methicillin-resistant *Staphylococcus aureus*; *E. coli*, *Escherichia coli*; *P. aeruginosa*, *Pseudomonas aeruginosa*; *K. pneumoniae*, *Klebsiella pneumoniae*; *C. albicans*, *Candida albicans*

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consumption for washing. Factors such as washing frequency, washing temperature and drying methods influence the environmental impacts related to this phase. Additionally, drying and ironing are also important when process frequency, time and temperature are considered. These parameters can differ for each product depending on fiber characteristics as well as usage area and consumer behavior. For instance, products made of synthetic fibers are likely to be washed, dried and ironed at lower temperatures (Beton et al., 2006).

The end-of-life phase includes disposal treatments such as incineration, landfilling and recycling processes. The environmental impacts of this phase are small compared to the other phases. Additionally, recycling and energy recovery schemes can lead to negative contributions. The barriers in front of recycling are mostly technological because of prints on clothes, composite materials, waterproof applications etc. (Beton et al., 2006).

Efforts to reduce the overall impact of the textile garments should concentrate on all phases. When LCA is used as a tool for deciding on the best solution to create sustainable and eco-friendly products, the following parameters must be taken into consideration; reducing agrochemical use, consumption of sizing chemicals, developing easy-to-grow crop cultivations by replacing cotton with hemp or flax in production and processing phase, reducing washing temperature and tumble drying in use phase and promotion of biodegradability in end-of-life phase which are some of the determined options as stated in JRC's (European Commission's Joint Research Centre) scientific and technical report named Environmental Improvement Potential of Textiles. The textile market is dominated by cotton, followed by polyester fibers.

1.1. Cotton

Cotton is one of the main raw materials among all fiber types owing to large share in the textile market. Production of cotton requires fertilizer and pesticide use as well as use of cultivating machinery, cotton seed growing and irrigation processes and tractor use which all cause emissions. Nitrogen, phosphorus and potassium in fertilizers have been an impact on eutrophication. Also, using insecticides provides significant contribution on eco-toxicity. The impact of cotton fabric production is higher than other fiber types due to high amount of fertilizers and agrochemicals used during agricultural production (Beton et al., 2006; Pesnel and Perwuelz, 2011). Furthermore, cultivation of cotton requires large amounts of water, almost 99% of all water used. It is average 5690 m^3 per tone fiber, whereas polyester and rejenerated cellulosic fibers such as lyocell are not needed (Shen and Patel, 2010).

Pre-treatment is associated with cotton fabric scouring to remove substances which are found on the fiber during its growth. This process requires energy as an input and contributes to the overall impact. Finishing processes are also significant in all fiber types. High amounts electricity are responsible for impact on human toxicity due to emission of arsenic into the air stem arising from the production of copper wires which are used for distribution of electricity (Beton and et al., 2006).

1.2. Polyester

Polyester is one of the widely used fibers in the textiles industry. The most significant contribution of polyester fiber is that it requires huge amounts of energy for its production. Therefore, polyester is an important agent to energy-related indicators such as climate change and ionizing radiation. While cotton is responsible for around 20 kg, the full life cycle of 1 kg of polyester fabric is responsible for release of more than 30 kg CO_2 equivalents to the atmosphere. Synthetic fibers have higher impacts because they intensively cause depletion of fossil resource than fibers produced by renewable resources (Beton et al., 2006). Global warming potential (GWP) 100 years of polyester fibers is 4.1 t CO_2 equivalent/t fiber, while GWP of cotton fibers is 2 t CO_2 equivalent/t fiber and 0.05 t CO_2 equivalent/t fiber for lyocell fibers in the cradle –to-factory gate (Shen and Patel, 2010).

The design of the product is the most significant stage in terms of this environmental approach. For example, it is possible to produce an item made of renewable, environmental friendly raw material and use a more eco-friendly production process. The use phase parameters can be regulated to more environmentally friendly implementations without compromising on cleaning and drying quality. Biodegradability of the materials is also another important function with regard to harmful impact on environment and people's health (Beton et al., 2006; Roos, 2015, Cleaner Production Institute, 2009; World Business Council for Sustainable Development, 2012; Arshad and Mujahid, 2011).

The correlation between green design and lifecycle environmental impacts shows a significant difference between biopolymers and petroleum base polymers. Biodegradable polymers is top of the green design classification because of their low energy demand, use of renewable materials, and biodegradability (Tabone et al., 2010).

New generation eco friendly fibers such as polylactic acid, lyocell and chitosan fibers has been significant role in textile industry recent years.

1.3. Polylactic Acid Fibers (PLA)

PLA (Ingeo^{TM}) is new generation eco-friendly fiber. It is generated by converting corn starch into lactic acid and then polymerizing. It is spun by melt-spinning process. Compared to the solvent-spinning process applied for synthetic fibers, melt spinning process allows them to have lower environmental cost and the production type of fibers are gained a wider range of characteristics. It is both renewable and non-polluting (Dugan, 2001; Farrington et al., 2005).

Global Warming Potential (GWP) is one of the most important indicator used in LCA. The total net cradle-to-factory gate GWP of PLA (Ingeo^{TM}) is 0.62 kg CO_2 eq/kg. The contributions of various process steps in PLA production chain are 0.25 kg CO_2 eq/kg in corn production, 0.29 kg CO_2 eq/kg dextrose production, 1.16 kg CO_2 eq/kg in lactic acid production, 0.54 kg CO_2 eq/kg in lactic production, 0.20 kg CO_2 eq/kg in polymer production. On the other hand, the net CO_2 uptake from the atmosphere of PLA because of renewable resources is 1.83 kg CO_2/kg. In other words, the fundamental value for PLA is the CO_2 removal from the environment. Fibers made from fossil resources like polyester cannot provide any CO_2 removal. In addition, while primary energy of polyester is 70 MJ (HHV)/kg polymer, it is 40 MJ (HHV)/kg polymer for PLA (Vink and Davies, 2015).

One of the benefits of renewable polymers compared with petroleum base polymers is a drop in the emission of fossil fuel derived CO_2. The volume of PLA production in 2020 estimates 3.6 billion kg/year. If PLA polymers displace an equal amount of polyester polymers, 192 trillion Btus of fossil-derived fuel will be saved per year. This scenario will cause 10 million tons reduction in the emission of CO_2 (Gross and Kalra, 2002).

1.4. Lyocell fibers

Lyocell fiber is a cellulosic fiber derived from wood pulp made by a solvent spinning process. The wood pulp is dissolved in a solution of 'amine oxide' (usually *N*-methylmorpholine-*N*-oxide). The solution is spun into fibers and passed through a washing process. More than 99.5% of the solvent was recovered in the