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Araştırma Makalesi / Research Article

BIO-COMPOSITES: PROCESSING OF THERMOPLASTIC BIOPOLYMERS AND INDUSTRIAL NATURAL FIBRES FROM STAPLE FIBRE BLENDS UP TO FABRIC FOR COMPOSITE APPLICATIONS

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ABSTRACT: At ITA, a number of research projects have been carried out in the past few years to develop production and processing technologies for not only commercially available but also experimental biopolymers. The studies deal with establishing processing methodologies through the entire staple fiber processing chain and also creating a property profile for these biopolymers. The paper will, therefore, provide an overview of the investigations carried out at ITA on the processing of experimental biopolymers, biopolymer and long industrial natural fibre blends up to bio-composites.

Key words: Sustainability, biocomposites, biopolymers, textile manufacturing, natural fibres

BİYO-KOMPOZİTLER: TERMOPLASTİK BİYOPOLİMERLERİN VE ENDÜSTRİYEL DOĞAL LİFLERİN KOMPOZİT UYGULAMALARI İÇİN STAPEL LİF HARMANINDAN TEKSTİL YÜZEYİNE KADAR ÜRETİMİ

ÖZET: ITA'da son birkaç yıldır ticari polimerlerin yani sıra deneysel biyo-polimerlerin üretim ve proses teknolojilerinin geliştirilmesine yönelik çok sayıda araştırma projesi yürütülmüştür. Bu çalışmalar kesik elyaf üretim süreçlerinde üretim yöntemlerinin geliştirilmesi ve aynı zamanda bu polimerlere ilişkin özellik profili geliştirilmesi ile ilgilidir. Bu makale biyo-kompozit oluşturabilecek uzun endüstriyel doğal elyaflar ve deneysel biyo-polimerlerin üretim yöntemlerine ilişkin ITA'da yapılan araştırmalara bir bakış sunmaktadır.

Anahtar kelimeler: Süreklilik, biyokompozitler, biyopolimerler, tekstil üretimi, doğal lifler.

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1. INTRODUCTION

With the growing concerns on the availability and sustainability of raw materials for various manufacturing processes, research and innovation on the development of raw materials and energy sources based on the use of renewable resources have now become a world priority. Renewable raw materials have already found applications in the manufacturing industry for applications such as packaging and consumer goods. [1, 2] The integration of biopolymers in the textile industry has been limited to applications such as filaments (e.g. surgical sutures) and nonwovens (e.g. wipes, diaper and feminine hygiene). [3] One of the major reasons for the lack of initiative towards applying biopolymers for various textile applications is the lack of available information on the staple fibre spinning of biopolymers. With clear-cut processing techniques and a corresponding development of staple fibre products, the range of available biopolymer textile structures could be broadened, thus increasing the scope of application of biopolymer textile products [4].

One of the application areas targeted by such biopolymer structures could be the textile reinforced composite sector. However, the quality of these bio-composites needs to be upgraded so that they may compete on a technological basis with standard oil-based composites. This is crucial to increase the valorisation of these new products and to contribute to the strength of the bio-based economy that is in full expansion.

At ITA, a number of research projects have been carried out in the past few years to develop production and processing technologies for not only commercially available but also experimental biopolymers. The studies deal with establishing processing methodologies through the entire staple fiber processing chain and also creating a property profile for these biopolymers from the polymer up to the product, in this case for composite applications, Figure 1. The talk will, therefore, provide an overview of the investigations carried out at ITA on the processing of experimental biopolymers, biopolymer and long industrial natural fibre blends up to biocomposites.

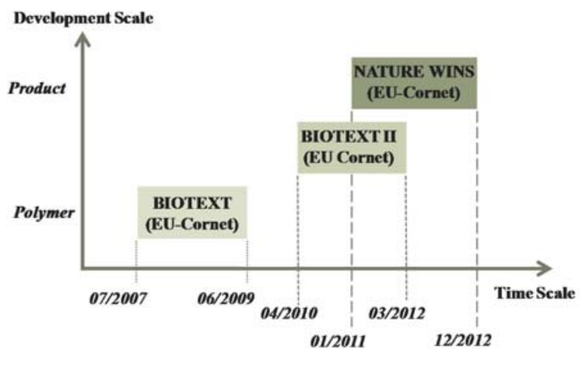

Figure 1. Research for bio-composites at ITA: from polymer up to the product

The CORNET (2007) project, BIOTEXT, investigated the properties and potentials of biopolymers in textile extrusion applications. The formulations of various experimental biopolymer combinations were optimized and their processability was evaluated. The property profiles of the acquired filaments were prepared and the possible end products were defined. The project thus established extrusion methodologies for new and commercially unavailable biopolymer formulations like PLA-PHB and blends of biopolyesters with starch. The project was in collaboration with ITA (Germany) and various other partners such as Centexbel (Belgium), ITCF Denkendorf (Germany) and AITEX (Spain).

Following BIOTEXT is the current CORNET (2009) project, BIOTEXT II, which has a similar collaborative partnership. The project aims at narrowing down the processing window of biopolymer melt extrusion for medical and technical textiles and further investigation of the processability of these polymers into nonwoven and staple fibre products. The range of polymers was narrowed to biodegradable polyesters (PLA, PHB) and starch polymers and their blends. At ITA, the parameters for the further steps in the textile processing chain for the production of nonwoven fabrics and staple fibre yarns are established.

With the process parameters established for the entire textile processing chain, the successive CORNET (2010) project, NATURE WINS, is more product-oriented. The project is in collaboration with Centexbel (Belgium) and Sirris (Belgium). The objective is development of composites from 100% renewable raw materials, with industrial natural fibres (INF) (flax, hemp) as reinforcements and biopolymer staple fibres (PLA) as matrix materials. The component fibres are blended and processed into an assortment of products with a range of structural geometries using various technologies. The textile structures are then condensed using compression moulding to form biocomposite prototypes for various applications like automobiles, sports and construction.

2. MATERIAL AND METHOD

There are several possible routes to produce fully bio-based composites. This work focuses on the development of bio-composites based on long/continuous industrial natural fibres as reinforcement and thermoplastic biopolymers as matrix material. The scope will be narrowed further on by focussing on a production route based on blending both matrix and reinforcement in fibre form and using compression moulding as composite formation process.

Figure 2, describes the textile processing chain for woven and knitted textile structures for composite applications. To produce the various textile structures, the manufactured yarns are produced from INF fibres, PLA fibers and their blends.

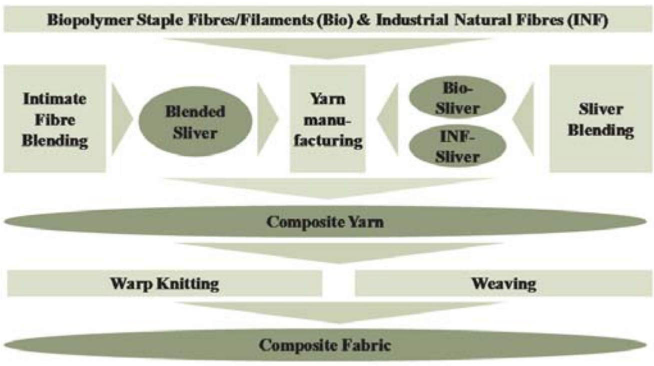

Figure 2. Processing composite fabrics out of Bio- and INF staple fibres

Staple fiber processing technologies for INF have been developed over the last decades and industrially established. However, to develop the bio-composite structures and enter the respective markets, it is crucial to modify spinning technologies to convert the biopolymer staple fibres into yarns. A number of papers and patents have been reported for the textile processing of biopolymers like PLA. However, commercial applications have been slowed down due to the inefficient knowledge transfer to the industry.

The first step for staple fibre spinning is backward planning and establishing process parameters throughout the spinning line. To narrow down the process window for biopolymer staple spinning with minimum expense of resources, the theory of solving inventive problems (TRIZ) has been applied. With TRIZ, the specific inventive problem is generalized and a search for the solution of generalized problem is carried out. The obtained general solutions are then applied to find a solution to the specific problem. With the application of this theory, the specific process of biopolymer staple spinning is generalized to manmade fibre staple spinning. Polyester was selected as the representative for the manmade fibres due its popularity. Moreover, biopolymers relevant to this work, (PLA, PHA) also belong to the family of polyester and hence would follow similar processing parameters. Hence to narrow down the range of process parameters for biopolymers, an analysis was carried throughout the spinning process i.e. from the filament stage to the formation of staple polyester yarn and optimum conditions of polyester staple spinning (100% and blends) were established. Consequently, the process for the staple spinning of individual bio-polymer or their blends was developed by applying the TRIZ generic solutions in each step of staple spinning system. For e.g. the rotor diameter, groove, speeds used for polyester rotor spinning was taken as a guideline for setting the process parameters for biopolymer spinning. Then optimizations of the process parameters were carried out for the staple spinning of the respective biopolymers.

The biopolymer filaments (PLA-1% PHB), extruded at AITEX, could not be texturized using the industrial opted method of false-twist texturing because of their specific thermal properties. Hence, filaments were texturized using air jet and knit-deknit texturing and cut into staple fibers. The fibers were processed into slivers using the micro dust and trash analyser (MDTA). Here, the fibres were also blended with cotton fibers in the ratios 50:50 and 70:30 (cotton:PLA). The slivers were then spun into yarns in the rotor sinning machine. Here the rotor speed and rotor diameters were varied to study the effect of these parameters on the yarn characteristics.

Microscopic structure of the textured yarns was viewed with a stereomicroscope Leica M295C to characterize the degree of texturing. The effect of texturing on the yarn characteristics was characterized using bulk (modified Dupont method) and instability tests (Dupont method). The yarn was characterized for mechanical characteristics like tenacity and elongation on a STATIMAT 4U tester according to the DIN EN ISO 2060 norms. Evenness and hairiness in the yarn were measured using Uster evenness tester. The effect on texturing method and the rotor spinning parameters on the above properties was studied.

Figure 3 describes the process chain for development of blended nonwovens from INF and PLA staple fibres. Different technologies (Air-laid and Roller-clearer card) will be used to control the orientation of the fibres to obtain unidirectional (UD) or multi-directional (MD) nonwovens. The structure of the composite will be also varied by intimately blending the fibers before forming the nonwovens or laying the individual INF and PLA webs on each other. The obtained blended nonwovens will be then needle punched to form a condensed nonwoven. These needle punched nonwovens will be converted into composites by compression moulding.

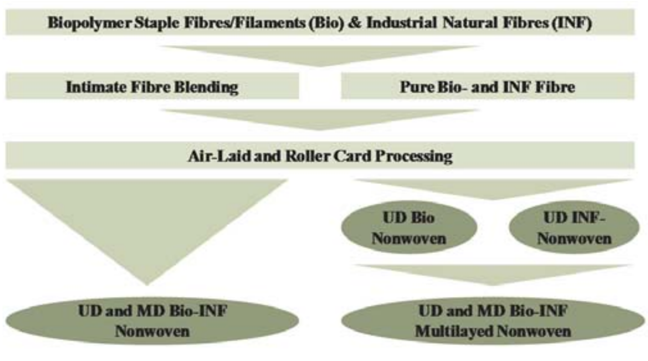

Figure 3. Processing non-wovens out of Bio- and INF- staple fibres

3. RESULTS AND DISCUSSION

Figure 4 shows the effect of the crimp structure imparted in the filament with texturing. This crimped structure is essential for the further processing to avoid problems such as roller lapping. The air jet textured yarn is characterized by its bulky, entangled structure while the knit-de-knit textured yarn has a more uniform loop structure. In the case of biopolymer yarns, the processability of air jet textured filaments was better compared to the knit-de-knit ones.

Figure 4. Texturing of PLA-PHB 1% fibres

Figure 5 shows the effect of air jet texturing parameters on the mechanical properties of the rotor spun yarns. It can be seen at low over-feed and pressure values, the tenacity and the elongation values of the spun yarns are the highest. At high over feed and pressure values, higher number of loops are formed to form a highly intertwined structure. Such a structure loses flexibility and hence the elongation value in the final yarn decreases. Moreover, the fibre orientation in such a structure is less parallel to the yarn orientation in comparison the fibre orientation of the untextured yarn.

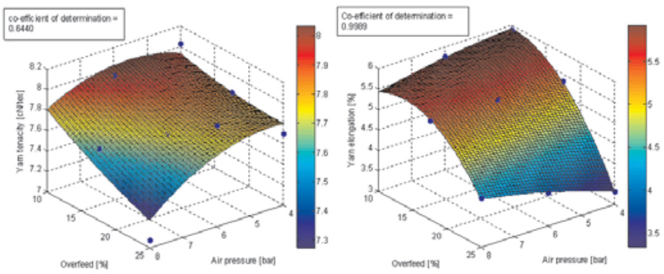

Figure 5. Effect of Air-jet texturing parameters on the Tenacity and Elongation of the staple yarn.

The textured filaments were cut to 38mm and processed in the MDTA3 to obtain slivers. The sliver made from 100% biopolymer was too weak to be processed further and hence the biopolymer fibres were blended with cotton in the ratio 30:70 (biopolymer: cotton) and then spun into yarns in the rotor spinning machine. Figure 6 shows the effect of rotor spinning parameters on the properties of the biopolymer-cotton blended yarns. It can be seen that the yarn elongation decreased at higher rotor diameters. With higher rotor speeds, the yarn tenacity increases while the elongation decreases. With high rotor speeds and high rotor diameters, the centrifugal force experienced by the yarn is high which makes the yarn compact, thus the tenacity of the yarn increases while its elongation decreases.

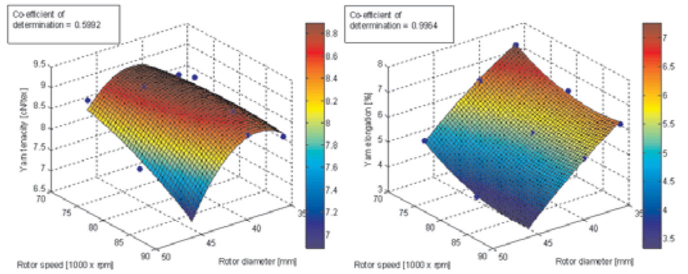

Figure 6. Effect of rotor spinning parameters on the Tenacity and Elongation of the staple yarn.

The composite core-sheet yarns are produced by using the DREF Spinning technology as shown in Figure 7.

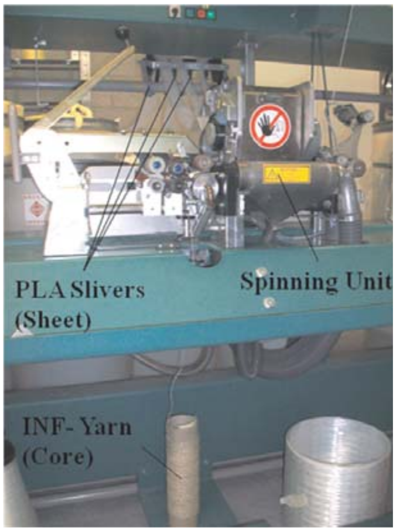

Figure 7. Composite yarn manufacturing by using DREF Spinning Technology.

The core sheet yarn manufactured with a 70 % core and 30 % sheet ratio is shown in Figure 8. The count of the composite yarn here is 100 tex. For processing the PLA slivers as sheet component, it was necessary to modify the process parameters as well as the spinning components.

Figure 8. Yarn manufacturing by using DREF Spinning Technology.

The production of composite yarns for woven and warp knitted fabrics are being undertaken during the tenure of the presented project. In cooperation with textile machinery manufacturing industry, the processes for manufacturing composite yarns will be modified further on to develop adequate spinning components and dedicated process parameters for the new raw materials. Further on the produced composite yarns will be used for woven and warp knitted fabric production.

4. CONCLUSIONS

The paper deals with processing of biopolymer fibres blended with industrial natural fibers for biocomposite applications. The conventional textile process chain needs to be modified in order to process these sustainable raw materials. To achieve the required quality, not only the processing parameters but also the machine components need to be modified. This work shows an overview of the potentials and the challenges involved in processing blends of industrial natural fibres and biopolymer fibres from staple fibers upto textile structures.

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