PROCESS DEVELOPMENT FOR UNI DIRECTIONAL TAPE STRUCTURE BASED ON RECYCLED CARBON FIBER AND THERMOPLASTIC FIBERS FOR FIBER REINFORCED PLASTICS

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ABSTRACT

The aim of present study is to develop a new process chain for the manufacturing of uni-directional (UD) tape structure based on recycled carbon and thermoplastic fibers. For this purpose, a process chain consist of carding, drawing and tape development processes was designed. Initially, technical and kinematical parameters of carding and drawing machines were optimized for the gentle processing of recycled carbon fiber. Furthermore, auto leveling unit of the drawing machine was also modified for uniform production of drawn sliver with minimum fiber damage. Finally, uniform sliver were processed on a prototype process to develop UD tapes for fiber reinforced plastics.
Key Words: Recycled carbon fiber, Tape structure, Recycled carbon fiber reinforced plastics, Thermoplastic composite

1. INTRODUCTION

Carbon fiber reinforced plastics (CFRP) are widely used in aerospace, defense, automotive, wind turbines, sports and construction industries due to its light weight potential and exceptional mechanical properties. However, the emerging problem associated with higher demand of CFRP is waste management, which originates from composite industry and end-of-life CFRP components in form of dry and wet waste. Furthermore, ecological aspects and new EU legislations also demands to find the new ways of recycling and processing of recycled carbon fibers for fiber reinforced plastics components [1].

In this context, extensive research has been carried out across the world in the last two decades to develop recycling techniques for CFRP waste. Consequently, mechanical, thermal and chemical recycling techniques are successfully adopted on commercial scale for the mass recycling of CFRP waste. Subsequently, different technologies are employed for the integration of recycled carbon fiber into fiber reinforced plastic with thermoplastic and thermoset polymers. The technologies used for the production of fiber reinforced plastics with thermoplastic polymers are injection molding, wet laid nonwovens and dry laid nonwovens techniques. The problem associated with these structures are poor fiber orientation, uneven fiber distribution and low uniformity. Therefore, these techniques are limited to develop composites for nonstructural applications [1-2].

To overcome this limitation, hybrid yarn technique were reported from *Institute for Textile Machinery and Textile High Performance Material Technology* (ITM), TU Dresden. In this technique, flyer spun twisted yarn was developed to produce thermoplastic composite with promising mechanical properties. In spite of this, potential of recycled carbon fiber is still not completely utilized. Furthermore, twisting mechanism involved in the spinning process exert very high torsional force that damage the carbon fibers. Moreover, twisted fibrous structure also disturb the fiber orientation in longitudinal direction that also effect the performance of the composite. In order to overcome these limitations, a new concept to manufacture a highly oriented, twist free hybrid fibrous structure will be here presented [3-4].

The aim of this project is to develop a process chain for UD tape structure based on recycled carbon and thermoplastic fibers for recycled carbon fiber reinforced plastics. For this purpose, technical and kinematical parameters of carding and drawing machines were optimized for the gentle processing of recycled carbon fiber. Then, uniform slivers were processed on a prototype tape development process to manufacture a thermally stable UD tape structure with promising mechanical properties. Finally, this tape structure was used to develop recycled carbon fiber reinforced thermoplastic composites. This process also has the potential to develop tape structure for recycled carbon fiber reinforced thermoset composites as well.

2. MATERIAL AND METHOD

2.1 Material

The tows of carbon fiber used in this study was purchased from SGL carbon, Germany. These tows were cut into defined length of 80 mm. The defined fiber length provide a real assessment of fiber damage on the each process. The polyamide fiber (PA-6) with 60 mm staple length was supplied by Barnet Europe, Germany.

2.2 Optimization of the carding process

The card machine employed in this study is a double cylinder card especially designed by **DILO Group and ITM for the processing of carbon fiber. This card machine has two** carding zones. Each carding zone has its own influence on carbon fiber. To understand the influence of each carding zone on carbon fiber, different technical parameters were optimized. The influence of these parameters on the behavior of carbon fiber was assessed in terms of fiber damage, fiber orientation and fiber cohesiveness.

2.3 Optimization of the drawing process

In order to produce uniform drawn sliver, drafting, auto leveling and control system of RSB D 40 RIETER drawing machine was also optimized. In auto leveling function, scanning roller are used to scan the feeding material under a certain pressure that generate an electrical signal. This electrical signal is processed by a digital signal processor that control the draft to produce uniform drawn sliver. The amount of pressure on scan rollers is 800 newton. In case of carbon fiber, this pressure crush the carbon fiber due to its brittle nature. For this purpose, pressure on scan roller was reduced through modification in auto leveling mechanism. The influence of this auto leveling parameter on the quality of leveling and fiber length were also studied.

2.4 Development of tape technology

The prototype process has been developed in ITM to produce UD tapes based on recycled carbon and thermoplastic fibers. This process contains a 3/3 drafting system, thermo fixation unit and winding section. In this process, multiple drawn sliver are drafted and converted into UD tape structure having defined fineness and thickness. Then, thermo fixation unit consists of infrared rays melt the polyamide fibers. Finally, a thermally fixed, stable and flexible tape structure is wound on a package. This process can also develop a non-consolidated UD tape structure for fiber reinforced thermoset composite as well.

2.5 Manufacturing of thermoplastic composite

In order to produce thermoplastic composite, different layers of UD tapes contain 60% recycled carbon and 40% polyamide fibers are combined to develop a composite plate having dimensions of 270mm × 270mm × 1mm. Then, these layers were consolidated by using a laboratory press machine P 300 PV from company Dr. Collin GmbH, Germany.

2.6 Material Characterization

The different characterization techniques were employed for sliver, tape and composite structure. The fiber orientation in card sliver was measured by **Lindsley method** [5]**.** The length of recycled carbon fiber in card and drawn sliver was measured by Image Analysis method [6]. The fiber to fiber cohesion in card sliver was assessed by Rothschild sliver cohesion meter R-2020. **The weight of specific length of sliver was used to measure sliver linear density. The quality of leveling was measured by sliver protocol test described by Rieter in** RSB D 40 technical manual. It is represented in terms of CV% (1m) in sliver. The thickness and areal density of the tape structure is also measured. The tensile properties of the thermoplastic composite was measured according to DIN EN ISO 527-5. For this purpose, specimens of 250mm × 250mm × 1mm were cut from the consolidated plate and subjected to Zwick Z 100 material testing machine from Zwick GmbH and Co., Germany for testing.

3. RESULTS AND DISCUSSION

3.1 Optimization of carding process

To understand the influence of each carding zone on sliver quality, speeds of breaker cylinder and finisher cylinder were varied. For this purpose, card slivers were produced according to different factors and levels combinations. The effect of speeds of breaker cylinder (Xv) and its worker (Xa) on fiber orientation is shown in the Fig. 1(a). It is depicted from the graph that lower speed of worker with higher speed of breaker cylinder yields maximum fiber orientation. It is correlated with the degree of carding action. The impact of speeds of finisher cylinder (Xt) and its worker (Xa) on fiber orientation is also shown in the Fig. 1 (b). It is interpreted from the graph that finisher cylinder has a significant effect on fiber orientation. The fiber orientation is increased with increasing the speed of finisher cylinder. It is due to the intensive carding action between cylinder and worker [5, 7].

The impact of speeds of these cylinders on mean fiber length is also given in Fig. 2.The results shows that mean fiber length of carbon fiber are better at higher breaker cylinder (Xv) and lower worker speeds (Xa). The same values are also obtained at lower level of breaker cylinder and higher level of worker speeds. It is because higher speed of breaker cylinder gives maximum fiber opening. The impact of speeds of finisher cylinder (Xt) and its worker (Xa) on mean fiber length are shown in Fig. 2 (b). It is depicted from the graphs that higher speed of finisher cylinder has a positive effect on mean fiber length. It can be correlated with the better fiber orientation [7].

The influence of speeds of these cylinders on sliver cohesive force are presented in Fig. 3. It is interpreted from the graph that speeds breaker cylinder (Xv) and its worker (Xa) have no significant effect on sliver cohesiveness. A similar effect has been observed in case of finisher cylinder (Xt) and its worker (Xa).

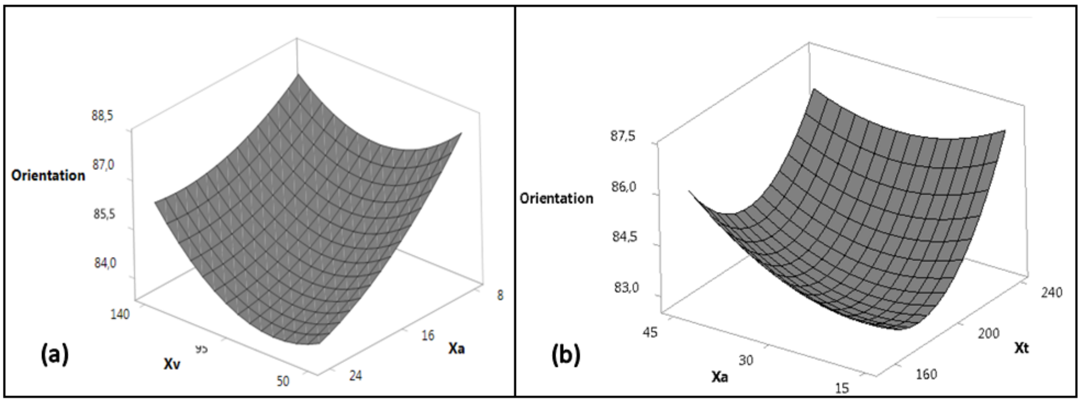

Figure 1. Influence of speeds of cylinders on fiber orientation

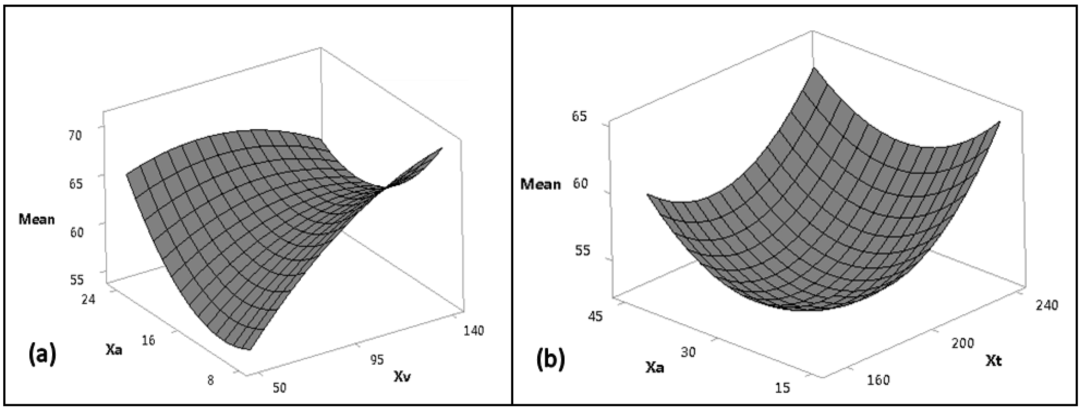

Figure 2. Influence of speeds of cylinder on carbon fiber length

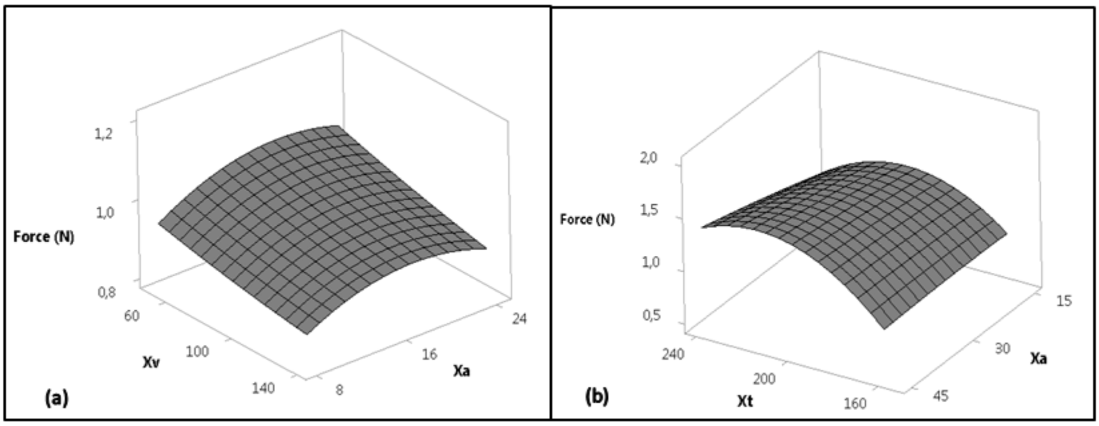

Figure 3. Influence of speeds of cylinder on sliver cohesive force

3.2 Modification in the auto leveling unit of draw frame

In order to produce drawn sliver with minimum fiber damage and highest level of sliver uniformity, drafting section, auto leveling unit and control systems of RSB D 40 RIETER draw frame were modified. It is interpreted from the Figure 4(a) that pressure on scan roller has a significant impact on carbon fiber length. While Figure 4(b) represents the leveling quality at different pressures of scanning roller. It is depicted from the graphs that low pressure on scanning roller can also produce uniform drawn sliver with minimum fiber damage as compared to sliver processed without auto leveling. In next step, further investigations will be conducted to modify the scan roller material and pressure to further reduce the fiber damage.

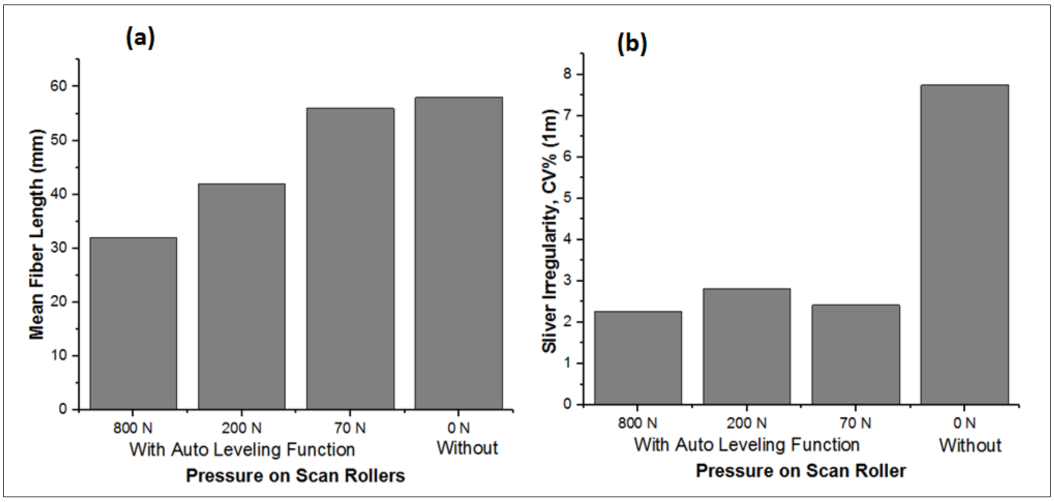

Figure 4. Influence of scan roller pressure on (a) fiber length (b) quality of leveling

3.3 Development of Tape Technology

In order to produce UD tape structure, a prototype process has been developed in *Institute for Textile Machinery and Textile High Performance Material Technology* (ITM) as shown in the Fig. 5 (b). Initially, twelve drawn sliver, processing without auto leveling unit were combined and drafted through a 3/3 drafting system. Furthermore, drafted fibrous assembly were heated up to 280 °C in thermo fixation unit with a rate of 10 m/min. Then, a thermally fixed, stable and flexible tape structure was wound on a package as shown in the Fig. 5(c). Finally, multiple layers of this tape was subjected to consolidation cycle to prepare thermoplastic composite. In the next steps, composites with highly uniform slivers will also developed.

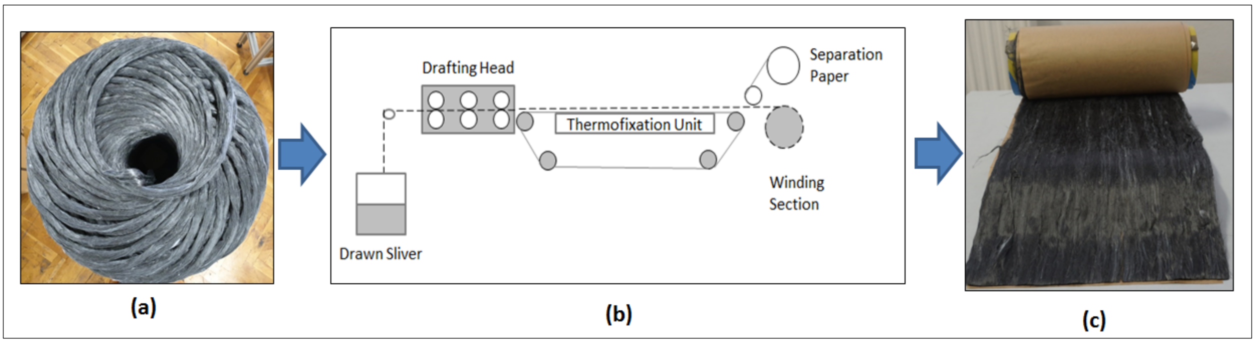

Figure 5. Tape development process (a) Drawn sliver (b) Principle of proposed setup (c) UD Tape

3.4 Mechanical properties of thermoplastic composite

The mechanical properties of the thermoplastic composites based on UD tape structure were determined by DIN EN ISO 527-5 standard test method. The mean tensile strength of the thermoplastic composite prepared from UD tape structure without auto leveling function is 602 MPa as shown in the Fig. 6. It is expected that tensile properties can further be improved up to 1000 MPa by developing a highly oriented UD tape structure with uniform drawn slivers. For this purpose, further investigation on drawing and tape development processes will also be conducted in the next steps. Furthermore, the influence of these parameters on the quality of sliver such as fiber orientation, fiber length and cohesiveness will also be examined.

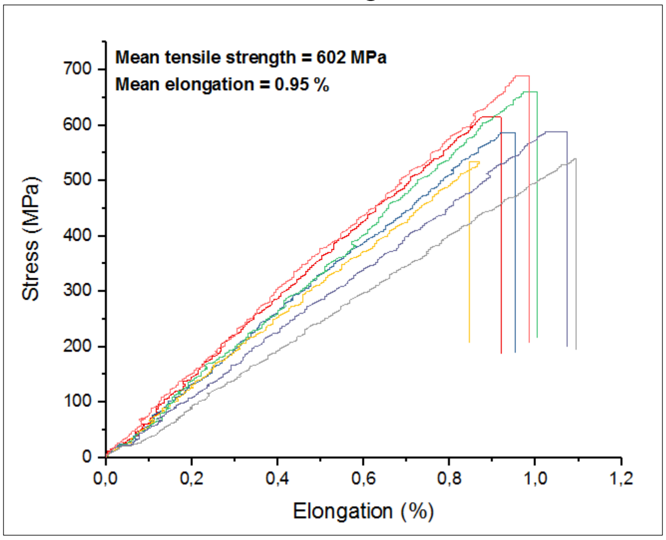

Table 6. Mechanical properties of thermoplastic composites prepared from UD tapes

4. CONCLUTION

The initial results of this study shows that UD tapes based on recycled carbon and polyamide fibers were successfully produced on a novel tape development process. Furthermore, fiber reinforced plastic produced from these tapes structure shows promising mechanical properties. In order to enhance mechanical properties, further modifications and systematic optimization will also be conducted in the next steps. It will lead to develop a fiber reinforced plastics for load bearing structural applications.

5. REFERENCES

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