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Properties of CF/PA6 friction spun hybrid yarns for textile reinforced thermoplastic composites

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Abstract. Due to their excellent strength, rigidity and damping properties as well as low weight, carbon fibre reinforced composites (CFRC) are widely being used for load bearing structures. On the other hand, with an increased demand und usage of CFRCs, effective methods to re-use waste carbon fibre (CF) materials, which are recoverable either from the process scraps or from the end-of-life components are attracting increased attention. In this paper, hybrid yarns consisting of staple CF and polyamide 6 (PA 6) are manufactured on a DREF-3000 friction spinning machine with various machine parameters such as spinning drum speed and suction air pressure. The relationship between different textile physical properties of the hybrid yarns, such as tensile strength and elongation with different spinning parameters and CF content of hybrid yarn is investigated. Furthermore, the tensile properties of uni-directional (UD) composites manufactured from the developed hybrid yarn shows 80% of the UD composite strength made from CF filament yarn.

1. Introduction

Due to their excellent strength, rigidity and damping properties as well as low weight, carbon fibre reinforced composites (CFRC) are widely used for load bearing structures. On the other hand, with an increased demand und usage of CFRCs, effective methods to re-use waste carbon fibre (CF) materials, which are recoverable either from the process scraps or from the end-of-life components are attracting increased attention. A major portion of such waste CF is available in the form of staple fibres ranging from 1 to 30 cm. In this drop back, extensive research works are being carried out worldwide on the development of hybrid yarns from staple CF by mixing with thermoplastic fibres. The objective is to apply such hybrid yarns for the manufacturing of textile reinforced thermoplastic CFRCs. So far, development of hybrid yarns from staple CF/ waste CF is reported using ring spinning [1]-[4] and wrap spinning [5],[6] process. Apart from these spinning methods, DREF-3000 friction spinning process offers added advantages including: higher productivity, and the customization of core-sheath ratio [7]-[9]. However, the potential of DREF-3000 friction spinning for the manufacturing of hybrid yarns from staple CF is not yet explored. The aim of the study is to investigate the potential of DREF-3000 friction spinning process for the development of hybrid yarns from staple CF for the application in thermoplastic composites. For this purpose, different hybrid yarns consisting of staple CF and polyamide 6 (PA 6) are manufactured on a DREF-3000 friction spinning with various machine parameters such as spinning drum speed and suction air pressure. The relationship between different textile physical properties of the hybrid yarns, such as tensile strength and elongation with different spinning parameters and CF content of hybrid yarn is investigated. Furthermore, the tensile properties of uni-directional (UD) composites manufactured from the developed hybrid yarns are also investigated.

2. Experimental

2.1 Materials

Different hybrid yarns with a core and sheath structure are developed for the investigations. The core of the hybrid yarns consists of two components:

- Component 1: consists of staple CF and PA 6 staple fibres. CF from SIGRAFIL C50 T050 EPY (SGL) of defined length (40 mm staple length) is used for the investigations. The fineness and strength of the individual CF is 0.67 dtex and 3.5 GPa respectively. PA 6 fibres from EMS Grilltech of 60 mm length with a fineness of 3.30 dtex are used. These staple CF and PA 6 fibres are used for the development of hybrid slivers, which is then supplied as the core.

- Component 2: a PA 6 filament yarn (Stilon, Poland). The fineness and strength of the filament yarn is 30 tex and 415 MPa respectively.

As the sheath of the hybrid yarn, a sliver of 4 ktex consisting of the same PA 6 staple fibres is used.

2.2 Development of hybrid yarns on a DREF-3000 friction spinning machine

For the development of slivers (used as the component 1 in the core of the hybrid yarns) consisting of staple CF and PA 6 fibres, both the fibres are mixed and carded to form a carded web. Two types of card webs are produced depending on the CF content such as 50 and 62 volume %. The carding is done by a modified laboratory long staple carding machine at the ITM. Afterwards, drafting is carried out on the card webs using a high performance draw frame RSB-D40 (Rieter, Ingolstadt, Germany) modified at the ITM for the processing of staple CF. The fineness of the produced draw frame slivers is approximately 3 ktex.
The hybrid yarns are manufactured on a DREF-3000 friction spinning machine (Fehrer AG, Linz/Austria) (Figure 1). For this purpose, the speed of yarn delivery and opening roller is kept constant at 50 m/min and 4500 rpm respectively, while spinning drum speed and air suction pressure are varied.

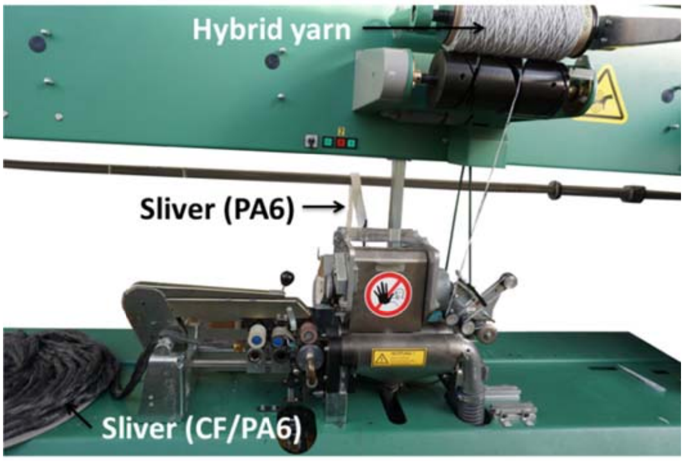

Figure 1: DREF-3000 friction spinning machine used for the development of hybrid yarns consist of staple CF and PA6 fibres

Different hybrid yarns of 800 tex fineness with varying core to sheath ratio and CF content, which are produced for the investigations are detailed in Table 1. The developed hybrid yarn FS#07 is shown exemplarily in Figure 2.

Table 1: Process variables and yarn specifications of the manufactured hybrid yarns

CF content of card web (volume %)	Spinning drum speed (rpm)	Air suction pressure (mbar)	Core to sheath weight ratio	CF content of hybrid yarn (volume %)	Yarn specification
50	1500	-13	70:30	28.3	FS#01
		-36			FS#02
	3000	-13			FS#03
		-36			FS#04
	3000	-36	80:20	33.4	FS#05
			50:50	19.1	FS#06
62	1500	-13	80:20	41.7	FS#07

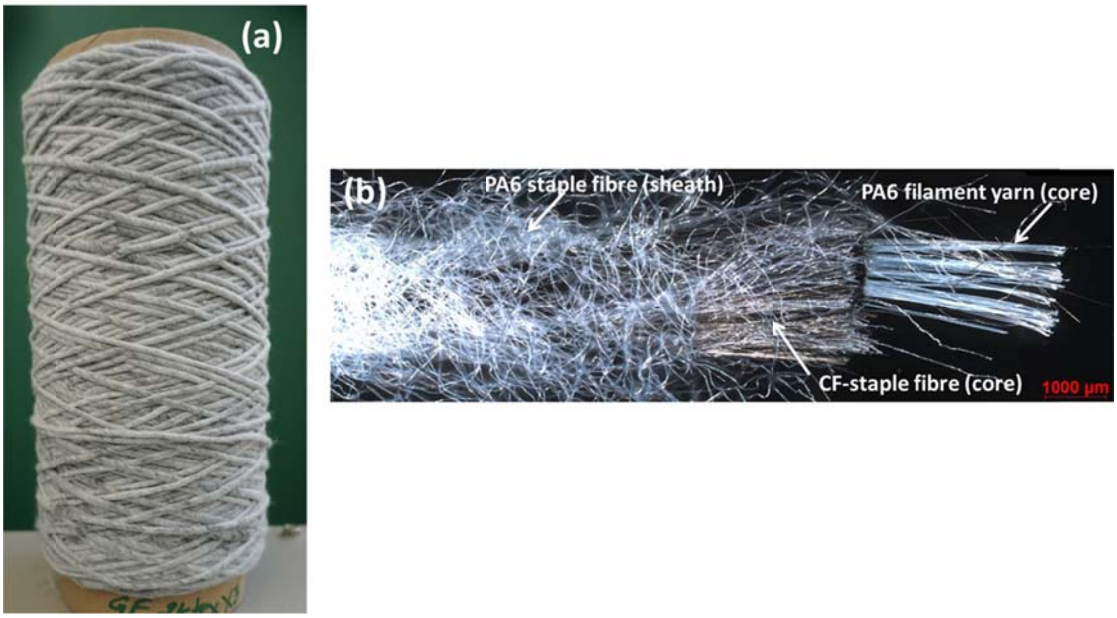

Figure 2: (a) Spool and (b) longitudinal view of the developed hybrid yarn (FS#07)

2.3 Characterization of tensile properties of hybrid yarns

Tensile tests of the manufactured hybrid yarns are carried out according to ISO 3341 using a tensile strength testing device Zwick type Z 2.5 (Zwick GmbH and Co., Germany) with special return clamps and external strain measuring. Samples of 250 mm yarn length are used. The test velocity is set to 100 mm/min and the initial load is kept at 0.5 cN/tex. The tensile force versus deformation is recorded and 10 measurements are taken to get the average value for each type of hybrid yarn. The stress-strain behaviour is evaluated using testXpert® software. The instrument is located in a temperature and relative humidity controlled laboratory maintained at 20 ± 2° C and 65 ± 2%, respectively.

2.4 Preparation of uni-directionally laid (UD) thermoplastic composite test specimen

Since, the ultimate aim for the development of the hybrid yarns is to manufacture thermoplastic composites, tensile properties of thermoplastic composites produced from the developed hybrid yarn are investigated. For this purpose a UD composite plate with dimension 274 mm×274 mm×1 mm is produced using the hybrid yarn (FS#07) as detailed in Table 1. It is to be mentioned here that FS#07 is selected for the investigations of composites considering its highest CF content in the hybrid yarn as CF content plays a vital role on the strength of composites. PA 6 corresponds to the matrix and staple CF to the reinforcement material of the composite.

The wrapping of the hybrid yarn is performed on a wrapping frame (IWT Industrielle Wickeltechnik GmbH, Germany), which is then consolidated by the Laboratory press machine P 300 PV (Dr. Collin GmbH, Germany). The consolidation is carried out by a computer-controlled cycle (under vacuum) comprised of a heating step from 30°C to 280°C. A pressure of 4 bar is applied from the beginning and up to the reach of 280°C. This pressure is kept constant for 600 sec at 280°C. Then the pressure is increased to 53 bar and finally, the temperature is dropped down to 30°C at 73 bar pressure.

Test specimens with dimensions of 250 mm×15 mm×1 mm are then cut out of the consolidated composite plates to carry out tensile tests in 0° direction according to DIN EN ISO 527-5.

2.5 Tensile testing of composite test specimen

The testing of the tensile properties of the UD thermoplastics composite specimen is performed on the testing device Zwick type Z 100 (Zwick GmbH and Co., Germany) in accordance with DIN EN ISO 527-5. A cross head speed of 2 mm/min and a test length of 150 mm are used for the tensile test. The elongation is measured using an optical sensor. A minimum of 10 measurements are taken to obtain the average value.

3. Results and Discussion

3.1 Mechanical properties of hybrid yarns

The results of hybrid yarn strength and elongation at break are presented graphically in Figure 3 (left) in the case of hybrid yarns produced from card webs with 50 volume % CF content and the core to sheath weight ratio of 70:30 in hybrid yarn. It shows there is a tendency that hybrid yarn strength decreases with the increase of spinning drum speed at constant air suction pressure.

The reason for the decrease of yarn strength can be explained in two ways:

- Firstly, a higher spinning drum speed through the friction drums leads to increased frictional forces between the fibre assembly (sleeve) and the friction drum surfaces, thereby increasing the torque acting on the fibre sleeve. As a consequence, the rotational speed of the fibre sleeve increases, which results in a higher yarn twist [10],[11]. Since the chance of damaging the CF core is higher due to higher twist insertion, the hybrid yarn strength decreases considerably with the increase of air suction pressure [12].
- Secondly, due to higher spinning drum speed, hooked wrapper fibres in the yarn may increase. As a result, wrapper fibres may not wound around the core and will not be efficiently contribute to the strength due to the decreased length [13].

However, the difference in hybrid yarn strength is not prominent in the case of hybrid yarns produced by varying air suction pressure at a constant spinning drum speed. Furthermore, the spinning drum speed and air suction pressure do not influence the elongation of hybrid yarns.

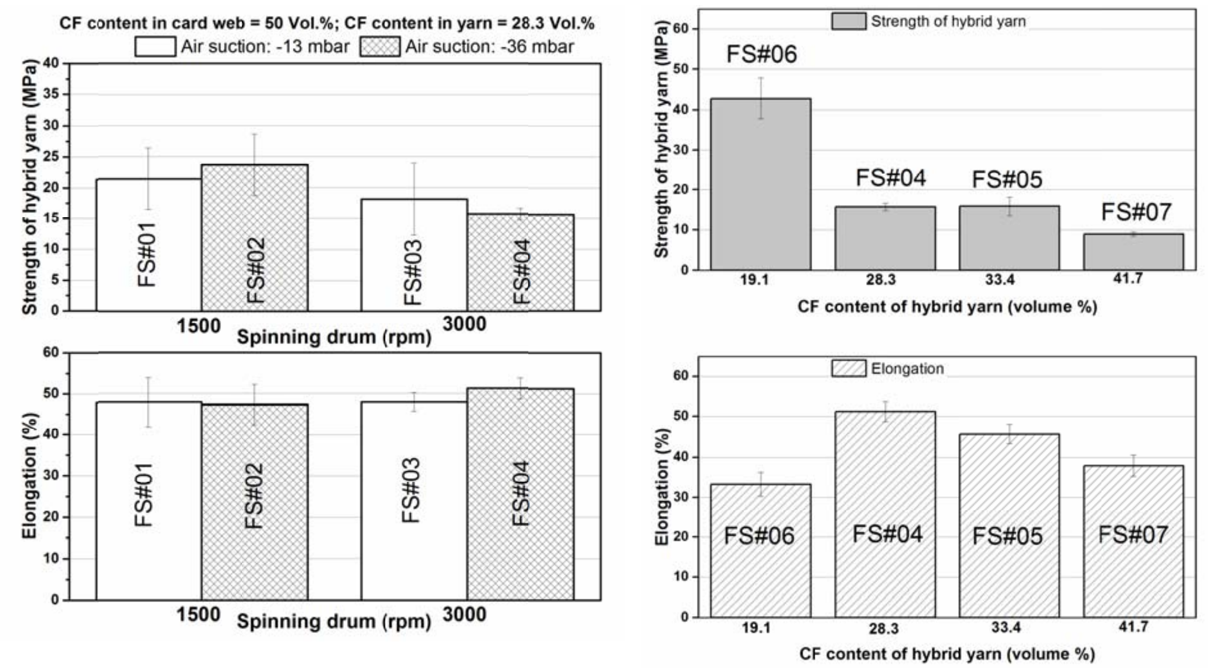

Figure 3: Strength and elongation at break of hybrid yarns depending on (left) spinning drum speed and air suction pressure at constant CF content of hybrid yarn and (right) variable CF content of hybrid yarn

In Figure 3 (right), the hybrid yarn strength and elongation at break are illustrated in the case of hybrid yarns produced from card webs with varying CF content in hybrid yarn. It shows that the hybrid yarn strength reduces significantly with the increase of CF content in hybrid yarn. The elongation at break of hybrid yarns increases with the increase of CF content up to 28.3 volume %, then it decreases gradually. The reason for lower yarn strength and higher elongation with higher amount of CF in hybrid yarn can be attributed to lower fibre to fibre adhesion because of smooth surface of CF.

The stress-elongation curves of hybrid yarns with varying CF content are illustrated exemplarily in the case of FS#06 and FS#07 in Figure 4.

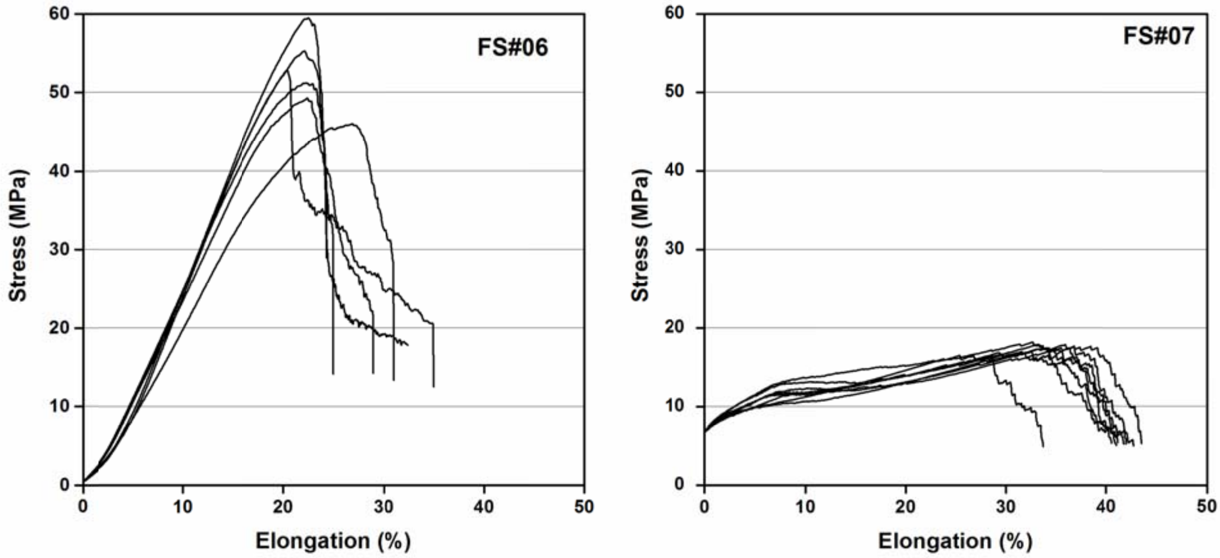

Figure 4: Stress-elongation curves of hybrid yarns

3.2 Mechanical properties of composite

Moreover, the tensile tests of the UD composites manufactured with the hybrid yarns reveal that it is possible to achieve a tensile strength of 839 MPa in 0° direction, which corresponds to approximately 80% of the tensile strength of composite made of CF filament yarn. The stress-elongation curves of the UD-composite manufactured from the hybrid yarn FS#07 are illustrated in Figure 5.

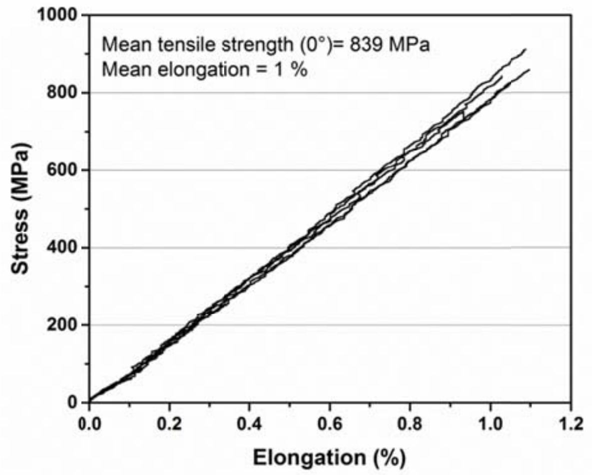

Figure 5: Stress-elongation curves of UD-composite manufactured from the hybrid yarn FS#07

4. Conclusion

The results of the investigations show that it is possible to manufacture hybrid yarns successfully using DREF- 3000 friction spinning machine from staple CF and PA 6 fibres with reproducible quality. The developed hybrid yarns show good textile physical properties to be processed further in different textile machines e. g. weaving, knitting etc. Furthermore, the tensile properties of the composite manufactured from the developed hybrid yarns shows that such composites can be applied for load bearing structures. With application of higher CF input length, it is expected that the strength of the composites can be further increased to a level of at least 90% of that produced from CF filament yarn. Because of the higher production speed of the DREF-3000 friction spinning machine can be used for the effective production of hybrid yarns from recycled CF.

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