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Microscopic Evaluation and Analysis on the Tensile Strength of Hybridized Reinforcement Filament Yarns by the Commingling Process

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Abstract

The analysis in this paper is focused on the pattern of mixing of filaments over a cross-section of hybrid yarns according to different combinations of reinforcement and matrix filament yarns through microscopic view. The volume content of filament in hybrid yarn cross-section was maintained at 50% for both reinforcement and matrix, and the hybrid yarns count at 600 tex throughout the experiments. It was observed from the experiments that diameters of reinforcement and matrix filaments have strong effects particularly on the pattern of mixing of filaments over a cross-section of hybrid yarns such that the hybrid yarns with more or less equal diameters of reinforcement and matrix filaments showed considerably even distributions over the hybrid yarn cross-section. This paper also investigates the possibility of hybridizing carbon/aramid, carbon/glass and aramid/glass matrices through the commingling process. In the experiment, several process parameters were selected and they include pressure, yarn oversupply-rate and different nozzle types. As a result of these experiments, it was concluded that the hybridized materials show better performance than individual reinforced filament yarns in terms of mechanical properties. For small tensile forces, the carbon/glass/matrix combination turned out to be good enough for general purpose applications.

Keywords

Light weight composite, hybrid yarn, hybridization, commingling process

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1. Introduction

Carbon fiber (CF), aramid fiber (AF) and glass fibers (GF) are inherently superior to conventional textile fibres in terms of mechanical properties as well as other chemical characteristics. Because of the inherent advantages and disadvantages associated with each material, it is better to hybridize them to fully benefit from their high performance in many practical applications [1–3]. The fibres produced in this process show the possibility of light weight composites as end products. Today these fibers are mostly used in high performance applications such as in the aerospace industry, geo-textile and auto industries, etc. [3]. Among the processes producing hybridized filament yarns, the commingling process, in which reinforcement filament yarns are well mixed together with the medium of matrix material such as polyether-ether-ketone (PEEK) or polyester (PES) or polypropylene (PP) filaments in one air stream. The commingling processes have been reported to achieve evenly distributed filaments over hybrid yarn cross-section [4–7].

The characteristic feature of commingling-hybrid yarns is that their components are distributed homogeneously enough over the yarn cross-section. Reinforcement filament yarns (carbon, aramid and glass) and matrix materials (polyester, polypropylene) have different diameters from each other [8]. These filaments can be mixed over yarn cross-section to give different yarn structures such as side-by-side (SBS), commingling (COM), etc. [5]. Yarn characteristics and properties vary depending on these structures. During these commingling process performed in the air texturising machine, the air jet nozzle is opened and both of these filament types are separated by the compressed air. This allows the filaments to be mixed with each other intensively in order to produce commingling yarn structure. This COM yarn cross-section has a homogeneous distribution of both reinforcement filaments and matrix materials. This method of opening and mixing directed towards homogeneous filament distribution is a most important factor for later usages of textile composites in which they may be required to bear greater tensile forces [6, 9]. In order to achieve this stage, texturising machine parameters such as air pressure, yarn over supply-rate, air jet nozzle type and filament diameters of both reinforcement filament and matrix materials are important [5–8, 10].

This study is focused on filament distribution over yarn cross-section of commingling-hybrid yarns through microscopic evaluation; suitable yarn and machine parameters were determined in order to obtain homogeneous filament distribution over COM yarn cross-section. Here, we also applied a modified air texturising machine [5] to produce the hybridized reinforcement filament yarns by a commingling process.

2. Experimental

The experimental setup is briefly summarized in the following but further details may be found in [5]. For this experiment, CF/GF, CF/AF and GF/AF matrix commingling-hybrid yarns were produced by using a modified air texturising ma-

Table 1.
Reinforcement filament and matrix filament yarn specifications

	CF	GF	AF	PP	PES	PEEK
Type	T300J	EC14-300E35/8	Twaron Type 2200	PP-IPF	Type 621	Z 4120
Count (tex)	198	300	161	5	5	46
No. of filaments	3000	770	1000	24	40	30
Filament diameter (μm)	7	14	12	17	9	39
Density (g/cm^3)	1.78	2.54	1.44	0.90	1.39	1.3

Table 2.
Working parameters used for commingling-hybrid yarns

Nozzle type	Wrapping air jet nozzle (Temco® LD5-series)
Yarn over supply rate	
Reinforcement filaments	1.5%
Matrix filaments	PES: 3.5%, PP: 5%, PEEK: 6%
Air pressure	4, 5, 6 bars
Working temperature	PES: 250°C, PP: 220°C

chine. As a matrix component, PP or PES or PEEK was used. Table 1 shows some technical data concerning the filament yarns employed in the experiments.

In the proposed process, two reinforcement filaments are fed on one side and the matrix material is supplied on the other side at the constant take-off roller speed of 50 m/min. Three types of nozzle are used in this work: a Texturising nozzle — Taslan® XV, a Wrapping nozzle — Temco® (LD 5.04, 5.05, 5.06 types) and and the Wrapping Hema-jet (T361 and T371 types). Air pressure supplied through the nozzles covers a range of 3–6 bars. Oversupply-rates of yarns are 1.5% for reinforcement filament yarns and 3.5, 5, 6 and 6.5% for matrix materials, respectively.

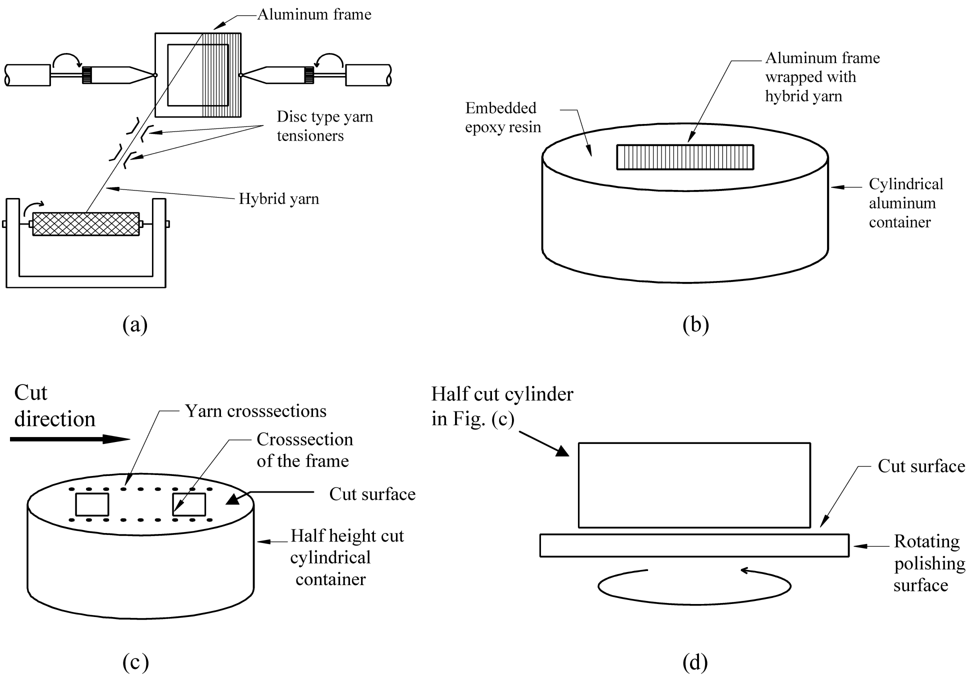
The temperature of the heating roller at the matrix filament yarn side is maintained at the working temperature of each matrix material: 380°C for PEEK, 220°C for PP and 250°C for PES, respectively [5]. The supply roller at the reinforcement filament side maintains a constant state at room temperature. The volume content of filament in hybrid yarn cross-section was maintained at 50% for both reinforced and matrix filaments and the hybrid yarns count at 600 tex, respectively. Based on the preliminary tests carried out, the processing parameters given in Table 2 were selected for further investigations.

Nine material combinations were selected with different volume contents and they are summarized in [5]. For further processing, a reinforcement to matrix filament combination was selected in the proportion 1:1, based on the previous results.

With this combination, the effect of different air pressures and material combinations was investigated in terms of tensile properties.

The volume content of filaments in hybrid yarn cross-section was maintained at 50% for both reinforced and matrix materials and the hybrid yarns count at 600 tex was selected. The reinforcement filament to matrix filaments combination was selected as 1:1. In this experiment, first each hybrid yarn sample was embedded in a resin material. This procedure is illustrated in Fig. 1.

First, a special aluminum frame was fixed in a special winding machine and hybrid yarn was guided through carefully controlling its tension by using disc tensioner devisors, on to the aluminum frame, as shown in Fig. 1(a). Each hybrid yarn package was mounted onto a frame, which enables the hybrid yarn package as in Fig. 1(a) to be rotated. The frame wound with hybrid yarns was placed in a central area of a small thin cylindrical aluminum container (holding by hand) and then, epoxy resin was carefully poured into that container as in Fig. 1(b) and allowed to cool for 24 h. After that, these containers were ground down by a grinding machine carefully to half of the height of the aluminum frame, as in Fig. 1(c). The cut surfaces were well polished with a special instrument as in Fig. 1(d). This step is important to get a clear view of embedded hybrid yarn cross-section through an electronic microscope.



(a) (b)

(c) (d)

Figure 1. Preparation of embedded hybrid yarn samples for electronic microscopic evaluation: (a) equipment used for winding yarns onto a frame; (b) wound frame embedded by epoxy resin; (c) side view of half height cut of cylindrical container; (d) polished cut surface.

In conventional procedures used in microscopic evaluation, it is possible to expand and/or contract the reinforcement and matrix filaments in the hybrid yarns during preparation. Then, the purpose of viewing the yarn cross-section to evaluate the filament distribution could be ineffective. However, by this procedure, the length changing problem of filaments and error interpretation possibilities during microscopic analysis were overcome. Then each sample was installed in an electronic microscope. This is shown in Fig. 2.

A video camera was attached and installed to the electronic camera and the microscopic view of the hybrid yarn cross-section was taken by the video-camera. Figure 3 illustrates certain views taken during the tests from an electronic microscope.

The effect of the diameters of reinforcements and matrix filaments is observed only for the distributions of filaments over the cross-section of hybrid yarn. The views were given the pattern of mixing of reinforcement and matrix filaments over a cross-section of hybrid yarn. Figure 3(a) shows that filaments are, for the most

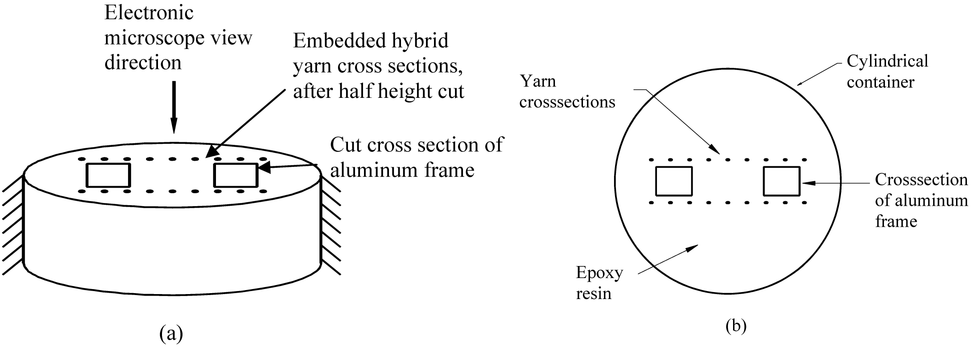


Figure 2. (a) Schematic diagram of electronic microscope viewing; (b) an overview of half cut aluminum container with an embedded hybrid yarn cross-section.

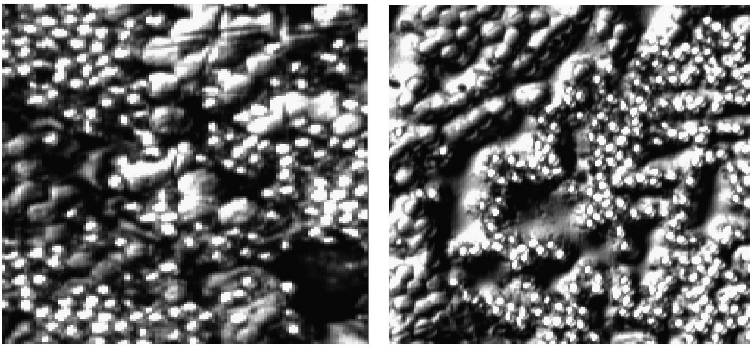

(a) (b)

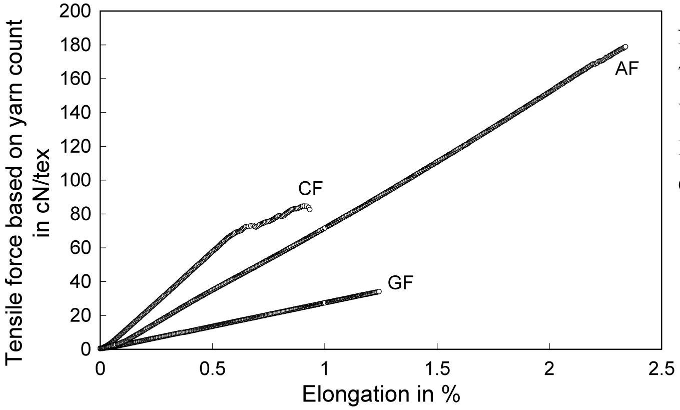
Figure 3. Cross-sections of some commingling-hybrid yarns: (a) CF/AF/PES-yarn cross-section; (b) CF/GF/PP-yarn cross-section.

part, evenly distributed over the hybrid yarn cross-section, because their filament diameters are approximately equal. The diameters were such as 7 μm for CF, 12 μm for AF and 9 μm for PES, respectively. However, in Fig. 3(b), filaments were distributed to a lesser degree of uniformity compared to CF/AF/PES hybrid yarn. This is the reason why the diameters of each filament type component show significant variations such as 7 μm for CF, 14 μm for GF and 17 μm for PP, respectively, as shown in Table 1.

3. Tensile Test and Results

A tensile test was performed to observe and to measure the tensile strength of selected samples. In order to observe these physical characteristics, a universal tensile test machine (Zwick, Type 1445) with special jaws (Type 8190), was employed. To measure the length changes of each sample, special measuring sensors were used, so that the elongation itself could be determined. Figure 4 illustrates the tensile force (based on filament yarn count) and elongation relationship of CF, AF and GF reinforcement filament yarns. The test was conducted under the following conditions.

At the beginning of the test, the relationship between the force and the displacement of CF, AF and GF types were recorded. Figure 4 shows the test results. It is shown in the figure that the CF type has the largest and the GF type shows lowest elastic modulus, respectively. It is interesting to note from the figure that the CF type specimen exhibits a kind of instability near breaking point, which means that it has a lower elongation property under tensile forces exerted on its cross-section. However, AF and GF types show better elastic characteristics throughout the entire range of stretching to breaking points than the CF type. Thus, according to this figure, it is also easy to identify that the AF type shows the better property in terms of stretch ability compared to GF and CF types. The tensile strength of AF type has shown higher values whereas the GF type shows lowest. The tensile strength



No. of tests = 20
Testing speed = 10 mm/min
Yarn length = 200 mm
Initial tensile force = 0.5 cN/tex
Clamping pressure = 3 bar

Figure 4. Relationship between tensile force and elongation of CF, AF and GF yarns.

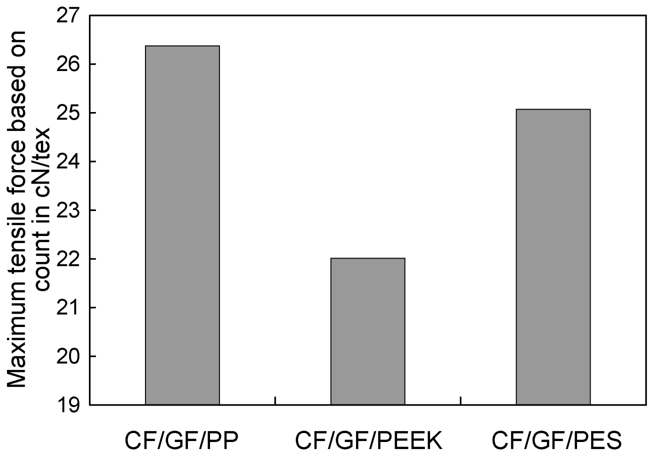


Figure 5. Maximum tensile strength of CF/GF matrix hybrid yarns based on yarns counts under air pressure of 5 bar.

of the CF type lies in between that of the AF and GF types, but it is more than 4 times higher compared to GF type. Therefore, we can see that each reinforced filament, which leads to the production of hybridized yarns, has advantages and disadvantages.

Figure 5 shows the maximum tensile force variation of some selected samples varying with the air pressure. Among selected samples, the GF/AF/PES was observed as the best combination since it shows the greatest tensile strength. It is seen from the figure that CF/GF/PES has the lowest tensile strength. This is due to tendency of higher filament breakages of CF and AF types compared to the other AF type. In experiments, we found that CF type has very much higher filament breakage than GF type and AF does not show any filament breakage. Based on this, the patterns of maximum tensile force variations of different hybrid samples under different air pressures can be justified. Thus, air pressure of 5 bar gives always better results, as indicated in Fig. 5.

Comparisons are made among the hybrid yarn samples with different matrix materials in terms of the maximum tensile strength based on yarn count. In Fig. 6, results are shown for CF/GF matrix samples. The air pressure for these experiments was fixed at 5 bar throughout the entire tests. From the Fig. 6, it is clearly shown that the CF/GF/PP combination has the highest tensile strength and CF/GF/PEEK the lowest, respectively.

4. Discussion

As illustrated in Figs 5 and 6, the maximum tensile strength of hybrid yarns produced in the proposed process varied with different air pressures applied to the experiments. At relatively higher air pressures, such as 6 bar, more filament breaks may occur easily than at lower air pressures. It is easily assumed that the breakage

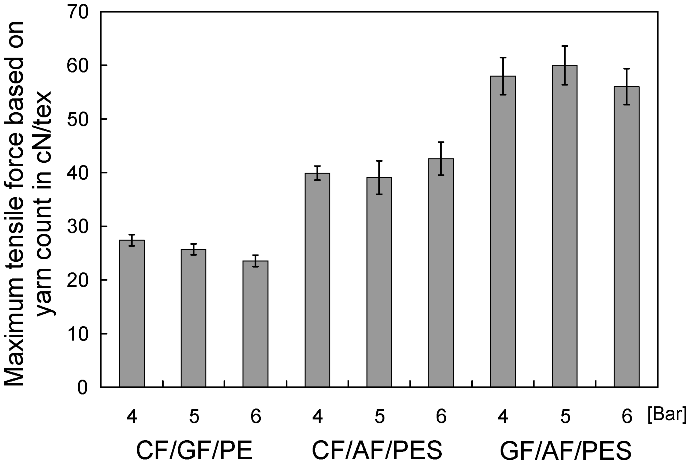


Figure 6. Relationships between maximum tensile strength and air pressure based on yarn count selected hybrid yarn types at the different air pressures for different material combinations.

of filaments reduces the ability to bear tensile loads. This would have serious consequences with hybrid yarns containing CF. The filament breakage of GF was found to be comparatively lower than that of CF. Therefore, the results are not much more unfavorable than that of CF.

Thus, at lower air pressures such as 4 bar, yarn structures do open well for better mixing of filaments on their cross-section. At higher air pressures, compact structure was observed, which also restricts filament distribution in addition to the filament breakages. Even filament distribution over yarn cross-section is a very important factor to bear tensile loads.

According to Fig. 6, PP and PES can bear more tensile forces than PEEK matrix filaments. During the breaking elongation tests, PEEK had a lower value than PP and PES with combination of reinforced filaments. The filament diameter of PEEK may be a reason for this, because it affects even filament distribution over hybrid yarn cross-section for bearing the stresses exerted on it. As a whole, PP and PES are suitable for high strength applications such as in some engineering applications.

The bulkiness of the hybrid structure determines the possibility of easy distribution of filament components. A more compact structure means less distribution of components over the hybrid yarn cross-section. The compactness of filaments in the hybrid yarn cross-section usually increases with the air pressure. However, a more open structure is not desirable regarding the load bearing function of hybrid yarns. Furthermore, it impairs other mechanical properties. Therefore, compact-open structures are preferable. Through the electronic microscope examination of hybrid yarn structures, it was possible to determine that a better combination of all three components (two reinforcement and matrix–filament types) took place when their filament diameters did not differ greatly.

5. Summary

It is concluded from the experimental work in the present study that a CF/GF matrix combination may be desirable for small tensile force applications, and CF/AF matrix and GF/AF matrix combinations for heavy tensile force applications. As a matrix material, PP and PES have shown better performance than PEEK in terms of tensile properties. It is also concluded from the experiments that air pressure of 5 bar is most suitable to assist the commingling process. At higher air pressures, compact structure was observed, which restricts filament distribution in addition to filament breakages. Based on the results obtained, the following possibilities could be also drawn for the preparation of commingling-hybrid yarns. Air pressure of 5 bar was more or less suitable to enable the commingling process. In yarn over supply rates, for reinforcement filament yarns 1.5% and for matrix materials 3.5–6% (for PES, 3.5%; and for PP, 5–6%) were the suitable ranges. Wrapping air jet nozzle (Temco® LD5-series) gave better hybridization with even filament distribution than other nozzle types. In order to get even filament distribution over the hybrid yarn cross-section, the filament diameters of the components have to be approximately equal.

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