ИЗСЛЕДВАНЕ НА МЕХАНИЧНИТЕ СВОЙСТВА НА ПЛЕТЕНИ БИ-, ТРИ-АКСИАЛНИ И ЕДНО-ОСЕВИ КОМПОЗИТИ ОТ ПОЛИПРОПИЛЕНОВИ И ТЕРМОПЛАСТИЧНИ СТЪКЛЕНИ ВЛАКНА

Каталин КЮСТЕР, Йордан КЬОСЕВ
Университет *на Долен Рейн, Факултет по технология на текстила и облеклото*
Институт по текстил и облекло
Вебшулщресе 31, 41065 Мюнхенгладбах, Германия
e-mail: Katalin.kuester@hs-niederrhein.de

INVESTIGATION OF THE TENSILE PROPERTIES OF BRAIDED BI-, TRIAXIAL AND UNIDIRECTIONAL THERMOPLASTIC GLASS FIBRE/POLYPROPYLENE COMPOSITES

Katalin KÜSTER, Yordan KYOSEV
Hochschule Niederrhein, Faculty of Textile and Clothing Technology,
Research Institute of Textile and Clothing
Webschulstrasse 31, 41065 Mönchengladbach, Germany
e-mail: Katalin.kuester@hs-niederrhein.de

ABSTRACT

Thermoplastic braided composites of glass and polypropylene commingled rovings are produced through an overbraiding process and the influence of different braiding parameters on the mechanical tensile properties of the composites is investigated.

Keywords: *braids, tensile, composites, glass fibres, polypropylene.*

Introduction

In recent years the European textile industry is subject to change, aimed at developing new high-performance products [1]. To meet the increasing demands in a wide range of applications, textiles are often not only used as single materials but as composites made of textiles and other materials. In particular these are applications where high mechanical properties with light weight are required, what often cannot be achieved with traditional materials like metals. The combination of reinforcing fibres with a polymeric matrix to composites is able to meet these requirements due to the high lightweight construction potential and offers extended performance capabilities in a wide range of areas [2].

More than 90% of the entire quantity of fibre-reinforced plastics is manufactured from glass fibres, which represent the most common reinforcing material [3]. In general glass fibres are characterized by their high strength combined with low density and elongation and their low elastic modulus in comparison to other reinforcing fibres [4]. They are resistant to heat and fire and show a good performance under thermal influences because of their low linear thermal coefficient of expansion [5]. The common used matrix systems can be divided into thermoplastic and thermosetting materials, which differ in their behaviour under thermal influence [2] and therefore as well in their processing. Polypropylene is a typical thermoplastic matrix, which is used usual because of its low costs [6]. From a technical process view, thermoplastics show to be advantageous as they enable short production cycle times, because in contrast to thermosetting materials, the often time intensively reaction or cross-linking time is not necessary [7]. Therefore the use of thermoplastics is aimed in the series production of the automotive industry to achieve shorter cycles [6]. Other advantages of thermoplastic materials are the reversible processing, as long as it is performed below decomposition temperature [2], the considerable shelf life, improved possibilities for recycling [7] and a higher energy absorption capacity due to the increased elasticity [6]. Thermoplastics are processed under temperature and pressure. In spite of melting, the still rather high viscosity can be a disadvantage of thermoplastics [2]. For that reason they are, besides the classic impregnation, often used in form of material blends. The commingling can be realized in form of hybrid yarns, which combine reinforcing fibres and thermoplastic filaments. The so reduced flow paths between the components to be connected improve the impregnation and bonding [7].

The textiles are used in different forms as reinforcing component in the fibre-reinforced plastic, which can be as single fibre or as textile fabrics for more complex parts [1]. The braiding technology turns out to be particularly suitable for the production, because as one of the most versatile and cost efficient processes [8], it offers optimal conditions for an economic production of textile semi-finished products and near-net-shaped preforms [9]. The biggest advantages of braiding are the various possibilities for the construction of the braided structures. The reinforcing fibres can be orientated flexibly in a wide range and the technology of overbraiding of shaped mandrels offers the opportunity to produce near-net-shaped preforms in a one-step process. The high flexibility in the design possibilities of braiding parameters offers a large variety of susceptible properties. Therefor the production of braided preforms is a complex procedure, which needs a careful preparation, appropriate equipment and planning of the design [10]. The relation between the structure and various properties can be a great help for the design of parts for many applications [11]. The aim of the current work is the investigation of the influence of different braiding parameters on the tensile properties of braided fibre-reinforced plastics. For this purpose different braided structures were produced and tested.

Experimental

A hybrid roving called TWINTEX® R PP from OCV Reinforcements is the base material for the manufacturing of the braided composites. It is a commingled roving of glass and polypropylene filaments with a glass fibre content of 60 percent by weight.

The production of the braids is performed on an overbraiding machine with 24 horn gears, where the braids are formed on a round mandrel. To reach an ideally dense appearance, a full carrier occupation according the pattern "1 full - 1 empty" is chosen. Biaxial, triaxial and unidirectional braids, each with three different take up speeds (1.5 m/min, 1.7 m/min, 1.9 m/min) in the braiding process are produced. ***Figure 1*** shows the three different braided structures with the same take up speed.

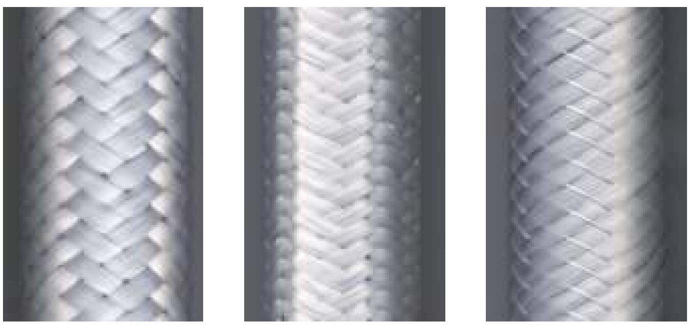

Figure 1 from left to right: biaxial, triaxial and unidirectional braid (1.7 m/min)

Subsequently to the braiding process, the braids are cut and the mandrel is removed. The consolidation and production of the composites is performed afterwards under the influence of heat and pressure within a thermal press. The cut braids are stacked with two layers and processed under the conditions of ***Table 1***. The cooling process takes place under a weighted plate.

Table 1

Condition of the thermal press

Braided structure	Temperature [ºC]	Pressure [bar]	Time [sec]
Biaxial	190	4	10
Triaxial	190	4	20
Unidirectional	190	4	10

Testing

The consolidated braided samples were submitted to an optical analysis to examine the structural characteristics. Afterwards tensile tests were performed with a Zwick material testing machine.

Results and discussion

Within the optical analysis, the braiding angles of the different braided structures were measured. A direct correlation between the take up speed and the resulting braiding angle can be determined. An increasing take-up speed leads to a decreasing braiding angle. At the same time the cover factor decreases and the appearance of the braided structure gets more open. The slowest take-up speed, where it is possible to produce a proper braid without fibre breakage could be figured out with 1.5 m/min. ***Table 2*** shows the three different take up speeds, starting from the slowest possible speed, and the resulting braiding angles for the different structures.

Table 2

Braiding angles of the different braided structures

Take up speed	Biaxial	Triaxial	Unidirectional
1.5 m/min	62.7°	64.0°	61.6°
1.7 m/min	56.9°	56.4°	56.0°
1.9 m/min	53.9°	51.5°	53.0°

The stress strain behaviour of the three different biaxial braided structures is shown in ***Figure 2***. The structure with the lowest braiding angle of 53.9° (biaxial 1.9 m/min) shows with 20.96 MPa (s = 35.79) the highest tensile strength. An incensement of the braiding angle to 56.9° (biaxial 1.7 m/min) leads to a reduction of the tensile strength to 15.89 MPa (s = 0.88). The biaxial structure with the highest braiding angle of 62.7° has the lowest tensile strength of 8.63 Mpa (s = 1.37). All three structures show a non-linear curve progression, so that a substantial increase of elongation is recorded on a rather constant stress level. It can be assumed that this progression can be traced back to an occurring reorientation of the braiding yarns under tension. The yarns align themselves in direction of the influencing tensile force so that the braiding angle gets smaller.

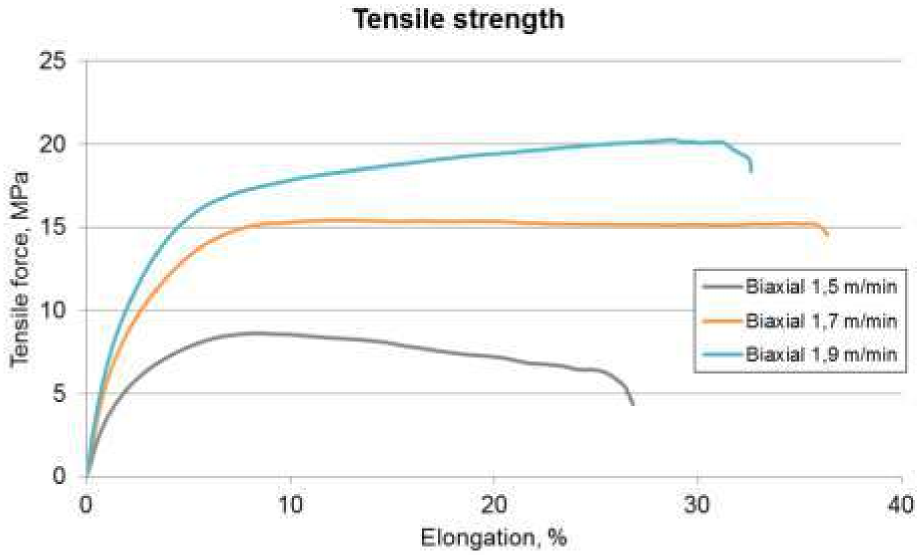

Figure 2 Stress strain behaviour of the biaxial braided structures

Figure 3 shows the stress strain behaviour of the triaxial braided samples. The structure with the middle braiding angle of 56.4° (triaxial 1.7 m/min) has the highest tensile strength of 119.99 MPa (s = 5.17). An almost identical strength of 117.59 MPa (s = 11.53) is reached from the samples with the smallest braiding angle of 51.5° (triaxial 1.9 m/min). As already seen for the biaxial braided structures, the braid with the highest braiding angle of 64.0° (triaxial 1.5 m/min) have the lowest tensile strength of 102.92 MPa (s = 6.56). Regarding the curve progressions, a nearly linear growth until the failure point can be recognized and the curves of all three structures show an almost identical shape. This suggests that the tensile force is primarily transferred to the axial inlay yarns and therefore no reorientation of the braiding yarns occurs.

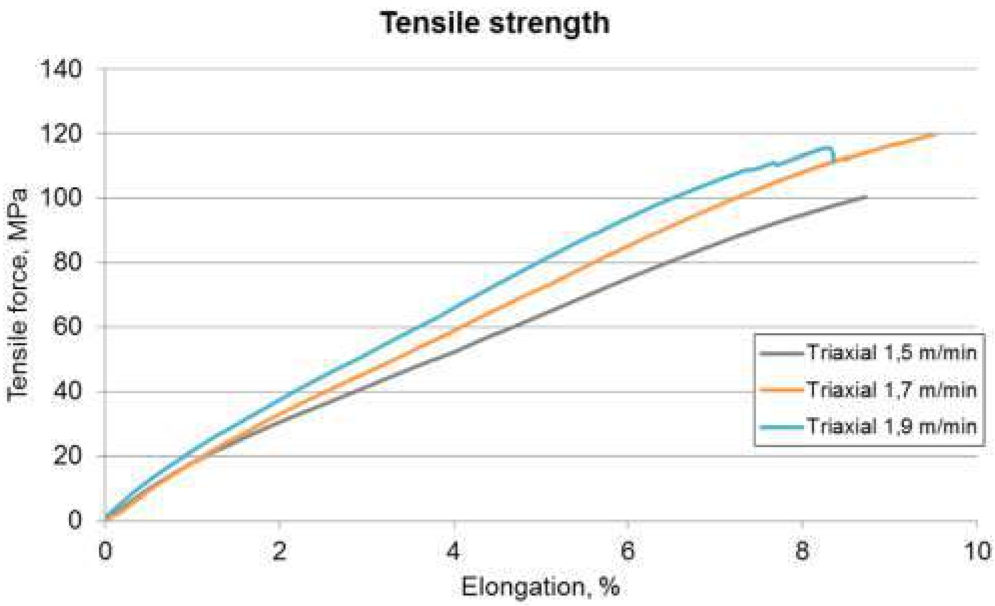

Figure 3 Stress strain behaviour of the triaxial braided structures

Considering the tensile strengths of the unidirectional braided structures in ***Figure 4***, it can be seen that the samples with the middle braiding angle of 56.0° (UD 1.7 m/min) reach the highest tensile strength of 4.86 MPa (s = 1.09). Slightly lower is the strength of the braid with the smallest angle of 53.0° (UD 1.9 m/min), which was measured with 4.17 MPa (s = 0.46). An increase of the braiding angle up to 61.6° leads again to an decrease of the tensile strength, so that the structure (UD 1.5 m/min) has the lowest strength of 2.55 MPa (s = 0.32).

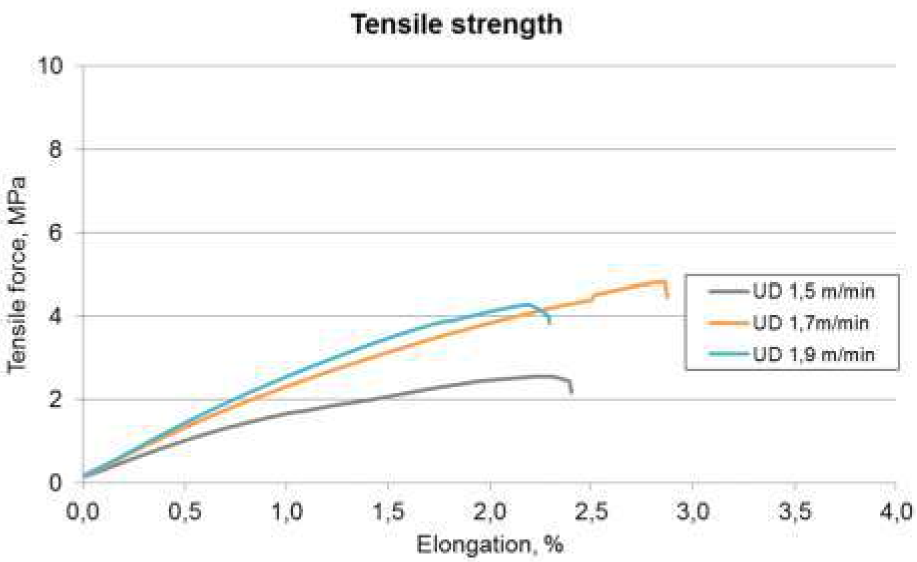

Figure 4 Stress strain behaviour of the unidirectional braided structures

A comparison of the tensile strength of all braided structures in ***Figure 5*** shows that the composites of triaxial braided structures have for all three braiding angles the highest tensile strengths. The average strengths of the three biaxial braids in comparison are reduced by 87%. The unidirectional structures only have average strengths of 3% in comparison to the triaxial braids. Regarding the influence of the different braiding angles, it can be seen that a larger braiding angle leads to a significant reduction of the tensile strength. This indicates that the structures are able to withstand the tensile force better, when the reinforcing fibres are orientated in direction of the applied force. Even though this assumption couldn't be approved for the smallest braiding angles of the unidirectional and triaxial braid because for both structures the middle braiding angle shows the best tensile strength. However for the triaxial braid it is only 2% higher and for the unidirectional braids 14% higher than the strengths of the samples with the smallest braiding angle and regarding the standard deviation, no significant difference can be seen. The biaxial structures show in comparison a significant decreasing trend of the strength with an increasing braiding angle.

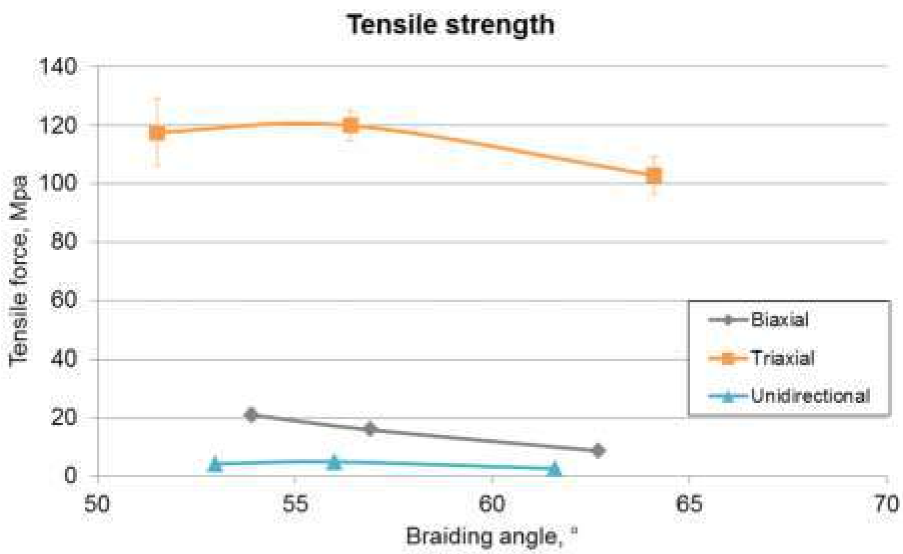

Figure 5 Tensile strength of all braided structures

A comparison of the elasticity modulus in ***Figure 6*** shows that the composite structures made of triaxial braids have as well the highest modulus. The average modulus is 69% higher than the average modulus of the biaxial braids and 97% higher than of the unidirectional braids. The lower elasticity modulus of the biaxial braids might be explained through the higher flexibility of the braiding yarns, which can be reoriented through the tensile force. The axial inlay yarns of the triaxial braids are able to withstand a deformation, which leads to a higher modulus. An increasing braiding angle leads to a reduction of the elasticity modulus for the biaxial and unidirectional braids. Because of the large standard deviation of the triaxial structures with the largest braiding angle, this assumption can't be confirmed or disconfirmed clearly for this structure.

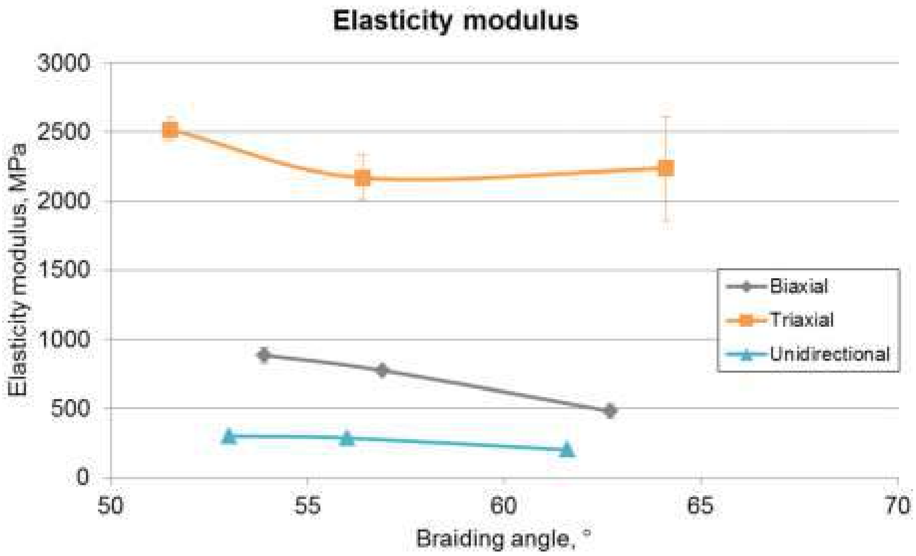

Figure 6 Elasticity modulus of all braided structures

Besides the different tensile strengths, the braided composite structures show as well rather different failure behaviours under tensile stress (***Figure 7***). The biaxial braids especially with lower braiding angles allow a distinct reorientation of the braiding yarns within the tensile test, which leads to a change in length and width of the samples. The movement of the yarns causes destruction of the polymeric matrix and the polypropylene strips away in form of fine dust. The final failure occurs in form of a fracture of the samples where the yarns partly break or are pulled out of the structure.

For all structures of the triaxial braids a break of the axial inlay yarns can be recognized. Moreover delamination of the two layers in the breakage area occurs. The triaxial structure with the highest braiding angle shows a break through the sample parallel to the braiding yarns. The braiding yarns in this area are not broken but slightly pulled out of their position. The triaxial structures with a smaller braiding angle show breaks of the axial inlay yarns and as well of some braiding yarns. Here the influencing tensile force seems to be carried not only from the inlay yarns, but as well from the braiding yarns, which are more orientated in the force direction than the braiding yarns of the structure with the largest braiding angle.

The unidirectional structures show with all three braiding angles a similar failure behaviour. All samples break in different areas between the braiding yarns, so that no yarn is damaged but the polymeric matrix fails.

Fig. 7 Failure behaviour of the different braided structures, left: biaxial, middle: triaxial, right: unidirectional

Conclusion

With regard to the influence of different braiding parameters on the tensile properties of braided composites, it can be seen that the adding of an axial inlay yarn leads to a significant improvement of the tensile strength, as the highest strength could be investigated for the triaxial braided structures. These samples show at the same time the highest elasticity modulus. The composites made of the unidirectional braided structures have the lowest tensile strength and modulus. With the biaxial structures it was possible to determine a clear influence of the braiding angle. Thus a decreasing braiding angle has a positive influence on the tensile properties. Furthermore it can be ascertained that the single structures have a rather different failure behaviour under the tensile stress. The biaxial braids allow a distinctive reorientation of the single braiding yarns until failure, which rather occurs in form of yarn pull-out instead of a break. For the triaxial braids it can be assumed that the tensile stress seems to be bearded mainly from the axial inlay yarns, because breaks only occur on these yarns and no reorientation of the braiding yarns could be found.

Summarising it can be said that triaxial braided structures are most suitable for the production of braided glass fibre reinforced thermoplastics because in comparison to the biaxial and unidirectional structures they lead to the highest tensile strengths. However it should be noted, that the adding of an axial yarn for the triaxial braided structures leads at the same time to an increasing mass per unit area and material usage. This in turn has an influence on the lightweight construction properties and the production costs. Finally the investigation shows that the structure of braided glass fibre reinforced thermoplastics has a significant influence on the tensile properties and should be taken into account for the design of composite structures.

Keywords: Fibre reinforced composites, braiding, glass fibres, thermoplastics

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