ASSESSEMENT OF DIFFERENT TECHNIQUES FOR ADDING THERMOPLASTIC MATRIXMATERIAL IN THE REINFORCEMENT STRUCTURES

Ruben Geerinck[1], Ives De Baere[1], Geert De Clercq[2], Jan Ivens[3] and Joris Degrieck[1]

[1]Department of Materials Science and Engineering, Ghent University
Technologiepark-Zwijnaarde 903, 9052 Zwijnaarde, Belgium
Email: Ruben.geerinck@ugent.be web page: http://www.composites.ugent.be

[2]Department of Textiles, Ghent University
Technologiepark-Zwijnaarde 907, 9052 Zwijnaarde, Belgium
Email: geert.declercq@ugent.be web page: http://www.ugent.be/ea/textiles/en

[3]Department of Metallurgy and Materials Engineering, KU Leuven
Kasteelpark Arenberg 44 bus 2450, 3001 Leuven, Belgium
Email: Jan.Ivens@mtm.kuleuven.be web page: http://www.mtm.kuleuven.be/English

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ABSTRACT

Fibre reinforced thermoplastics (FRTP) are becoming more and more an alternative for thermoset composites. Due to the viscosity of thermoplastics the production methods for thermoset composites cannot always be used. Therefore, new techniques have to be developed in order to obtain a high quality thermoplastic composite. This paper will give three possible manufacturing processes for these composites with the aid of textile processes. The different manufacturing processes of the fabrics all have in common that the thermoplastic matrix inserted during the production of the fabric (woven or knitted). As a result, this reduces the flow distance of the thermoplastic matrix which can increase the quality of the impregnation.

The first manufacturing process is pultruding the reinforcement yarns so the thermoplastic matrix is already in and around every yarn. A leno woven fabric is made from these yarns to test the impregnation. The second process is inserting thermoplastic weft yarns in a non-crimp multilayer fabric woven on a face-to-face loom. The third and last examined process is knitting a thermoplastic matrix around straight reinforcement yarns using a flat knitting machine. All fabrics are then pressed under high pressure and temperature to make a composite plate.

To conclude, all these studied techniques provide positive results that textile structures can be a good alternative for the production of FRTP.

1 INTRODUCTION

Fibre reinforced thermoplastics (FRTP) are a fast growing market. Production technologies for thermoset based FRP’s are not always usable for thermoplastics as they are too viscous. However, textile technology can provide solutions such as mixing reinforcement fibres with thermoplastic fibres so that the flow distance is reduced and the impregnation speed and quality is improved. This mixing can be done either within a yarn or by combining yarns of both types in textile structures such as woven or knitted fabrics. Another way to achieve these goals is coating the fibre bundles. These preforms offer two ways of producing composites (i) indirect one in which fabrics are first transformed into solid sheets by heating them under pressure, after which they are transformed into their final shape by thermoforming processes; and (ii) a direct one in which textile structures themselves are thermoformed into the final structure.

A first technology being assessed is yarn coating. Multifilament glass yarns were coated with PVC and used as weft yarns in leno woven fabrics. By adapting the warp tension, fabrics without any crimp of the weft yarns are obtained, i.e. with perfect UD glass yarns. These fabrics serve as textile preforms for FRTP. By thermoforming under pressure composite plates were manufactured.

If various layers of UD yarns are required a very apt way to produce them is multirapier weaving. The considered multilayer fabrics consist of five warp layers of UD glass rovings, six weft layers of polyester yarn and a fine glass yarn binding them in Z-direction. The obtained fabrics serve as multilayer textile preforms and composite plates were produced by thermoforming them under pressure. Although the process can be improved, this route shows an alternative for some applications if fine-tuned towards optimal weave and choice of thermoplastics.

The third structure under consideration is a knitted fabric made of thermoplastic yarns and UD glass yarns. These structures can also be transformed into composites by thermoforming under pressure. As the drapeability of knitted fabrics is very high, they can be pulled over complex moulds without wrinkling. However, these fabrics need to be tensioned carefully during thermoforming to straighten the glass yarns since otherwise they are curved.

2 MATERIAL AND PRODUCTION

2.1. Textile preforms

The first manufacturing process is pultrusion of the reinforcement yarns. Before the reinforcement yarns are used in the leno woven fabric, the yarns are coated with a thermoplastic matrix (PVC). Thereby two yarns are pulled through an extruder head. In this head the yarns go through a cone where a coating process takes place [1]. The reinforcement yarns go straight through the extruder head and the PVC is coated around these yarns as displayed in Figure 1.

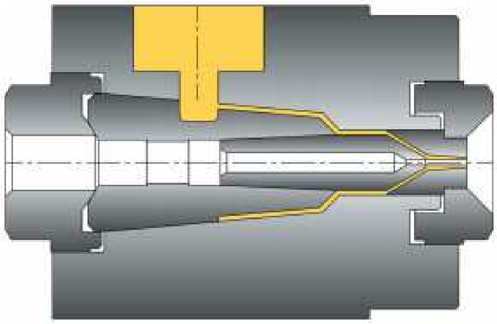

Figure 1 Extruder head

The diameter of the coated yarn depends on the speed of the extruder and at which speed the yarn is passing through. In this study yarns are produced with 0.44 and 0.55 mm diameter resulting in a 24 and 38% fibre volume fraction of the composite material.

The coated yarns are used as weft yarns in a leno fabric structure. The leno fabric also consists of two different PES warp yarns. One multifilament yarns for the straight warp yarns and one monofilament yarn for the winding warp yarns. The weft and straight warp yarns lie straight, so without bending, in the fabric. The pendulum warp yarns connect the two straight systems with a zigzag movement. In this study only the weft yarns are reinforced so a unidirectional (UD) fabric is produced. Figure 2 shows the leno fabric structure [2].

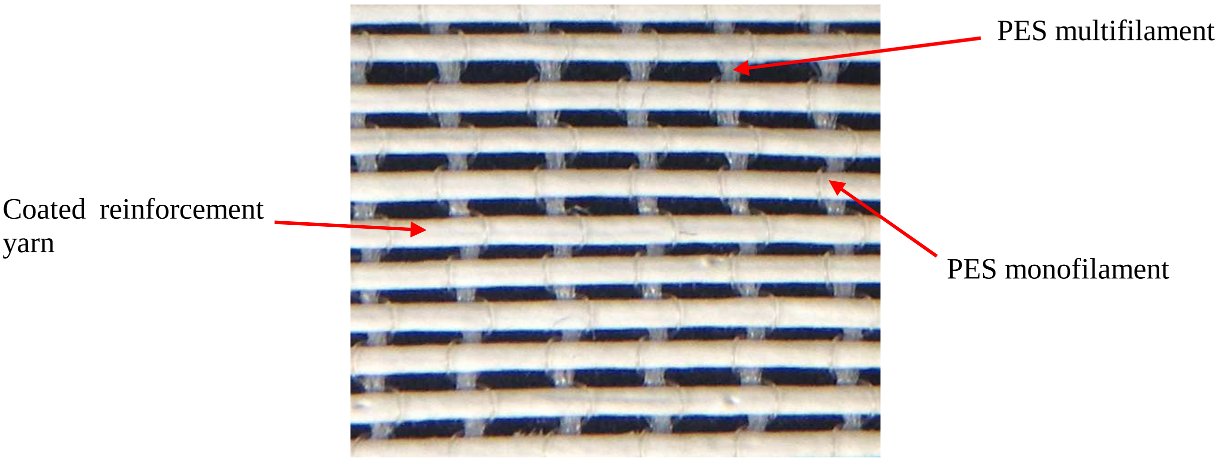

Figure 2 Leno fabric structure

The second manufacturing process is the production of 3D woven fabrics on velvet looms [3-4]. Normally, when producing velvet, two plain weaves are created which are held together by a third yarn system called the pile yarns. Later these pile yarns are cut, making that the two plain weaves have a side with cut yarns. This is normally the upper side and is known for its soft properties. To make a 3D-woven textile, the pile yarns are no longer cut so the connection between the two woven fabrics is maintained. In warp direction a glass fibre roving [5] is used, in weft direction the PES matrix and as connection yarn a multifilament glass yarn is used. To clarify this, Figure 3 illustrates how such a 3D-woven textile looks. The straight lines represent the warp yarns, the dots the weft yarns and the colored lines the pile yarns. On this schematic, it is clear that the warp and weft run straight through the textile, giving the textile the looks of a UD-material. Because of the glass pile yarns the chance of failure due to delamination is expected to be lower. Delamination is damage inside the composite that runs parallel with the fibre direction [3-4]. Three other woven fabrics will be tested in order to determine the effect of the different configurations of the pile yarns.

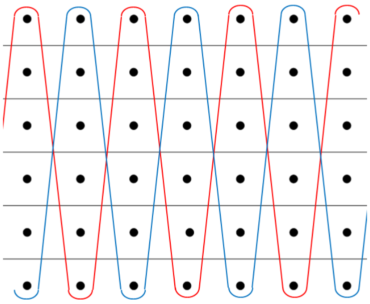

Figure 3 Schematic side view of the 3D woven fabric type 1

The third and last manufacturing process is producing knitted fabrics with glass and polypropylene (PP) fibres. Some yarn properties should be taken into account with respect to the knitting process. The most important properties for knitting are friction, abrasion and suppleness, which makes it hard to work with glass. In order to solve this, ceramic materials are used to guide the glass fibres.

In order to produce bi-axial knitting, it is required to acquire a new supply system to get the yarns transverse on the production direction in the knitted fabric. The principle is shown in Figure 4 where an additional lath is placed in which tubes have been anchored through which the glass fibre runs to the knitted fabric.

Figure 4 Supply system for bi-axial reinforcement

Some more modifications at both sides of the machine were required to regulate which the angle the yarns make with the incorporated lath. If this angle is too large, the filaments of the glass yarns break while the machine is running, if too small, there is too much friction between the yarn and the tubes, leading to failure of the yarn as well.

To test the added value of the bi-axial reinforcement compared to a structure with mono-axial reinforcement, composite plates will be made out of both knitted fabrics. Also, the influence of the knit stich and the amount of glass fibre will be tested.

While making knitted fabrics with different fractions of PP and glass, it appeared that simply changing the amount of used yarns was enough to reach that goal. In other words a change in programming was not required.

The final knitted preform is shown in Figure 5.

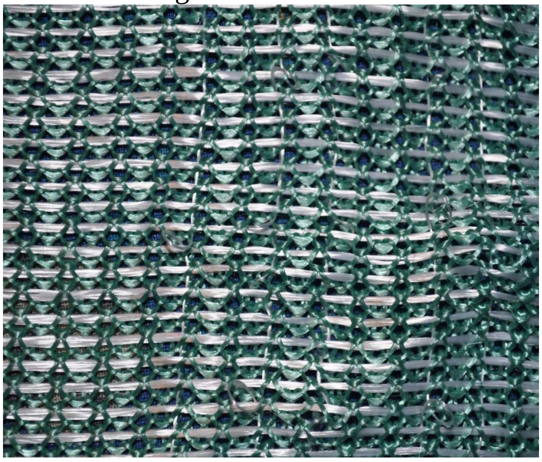

Figure 5 Knitted fabric

2.2. Production of a composite plate

Composite plates are produced from the made preforms with a Pinette Press Zenith 2 (Figure 6). First the desired stacking is placed between two heated plates (red circle in Figure 7) in a spacer so the thermoplastic matrix melts. In combination with pressure, the thermoplastic matrix flows in the reinforcement yarns to maximize the impregnation. This pressure is also needed to remove the air out of the composite so the number of voids are minimized. Afterwards, the composite plate is placed between to two cold plates (blue circle in Figure 7).

Figure 6 Pinette Press Zenith 2

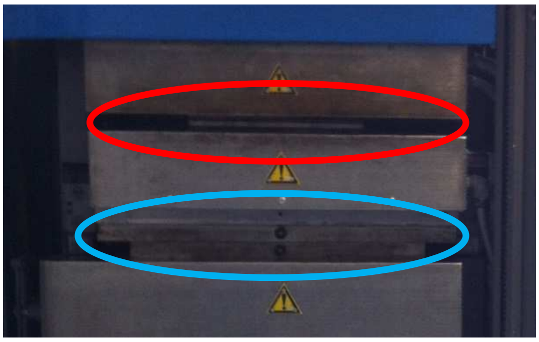

Figure 7 Detailed view Pinette Press Zenith 2

In the table below (Table 1) the different conditions for the production of the composite plates are listed. The PVC of the pultruded reinforcement yarns melts at 180°C but 200°C is chosen to decrease the viscosity. An even higher temperature caused to much degradation of the PVC (discoloration) [6]. A pressure of 10 bar is used to close the hot plates and to remove the air to avoid voids. To maximize the impregnation the composite plate is thermoformed during 20 minutes. Also for the woven preforms the temperature is a key parameter: dropping below 255°C, the PES will not melt; going over 270°C, the PES will degrade due to hydrolysis [6].

	Leno preform	Woven preform	Knitted preform
Temperature (°C)	200	260	220
Pressure (bar)	10	15	10
Time (minutes)	20	12	20

Table 1 Conditions for the production of the different composite plates

2.3. Evaluation of the impregnation

The impregnation of the reinforcement is assessed by microscopic examination. For the leno woven pultruded reinforcement yarns the maximum impregnation of a fibre bundle with these conditions is 2/3, as shown in Figure 8. Figure 9 displays the impregnation of the multi-layered woven fabric. This impregnation is, as the impregnation of the knitted fabric (Figure 10) better as it does not show any dry spots or voids [7].

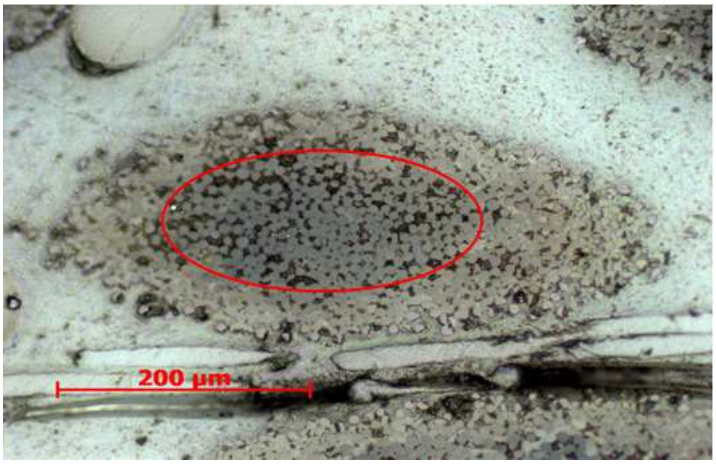

Figure 8 Impregnation of a single pultruded fibre bundle

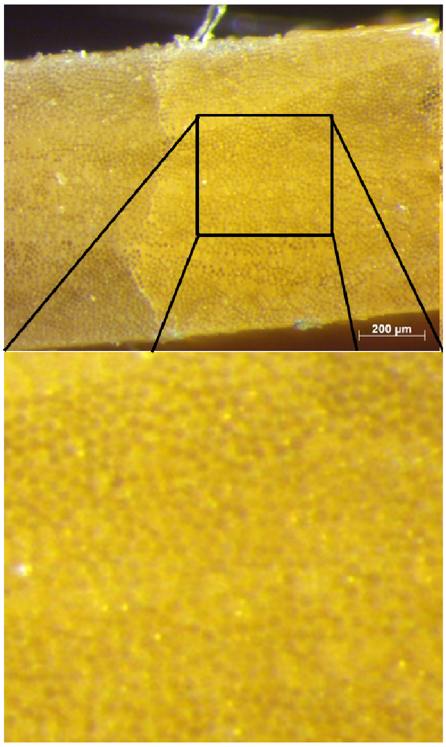

Figure 9 Impregnation of the 3D woven fabric

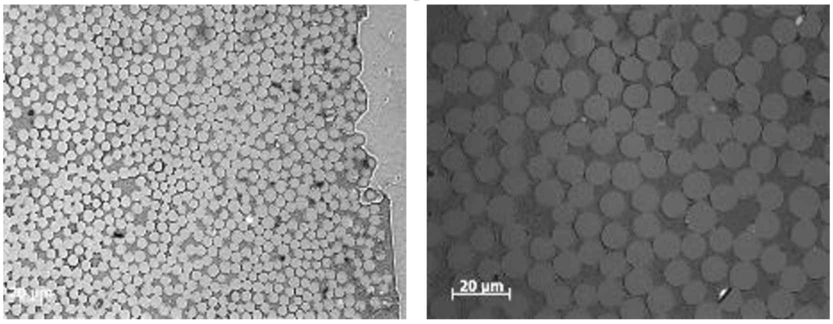

Figure 10 Impregnation of a knitted preform

3 MECHNICAL CHARATERIZATION

The elastic properties of the different composite materials are evaluated by performing tensile tests according to the international standard ASTM 3039. Specimens (25 x 250 mm) are tested on an Instron 8801 hydraulic tensile machine with 8800 FastTrack Controller, alignment cell, anti-rotation head and a 100kN loadcell. All specimens are provided with two strains gauges, one longitudinal and one transverse so Young's modulus and Poisson's ratio can be determined.

For the leno woven pultruded reinforcement yarns Figure 11 illustrate the stress as function of the strain for a composite plate with a UD stacking of eight layers with a fibrevolumefraction of 24%. The curves are shifted over a certain distance at the x-axis to beter visualize the results.

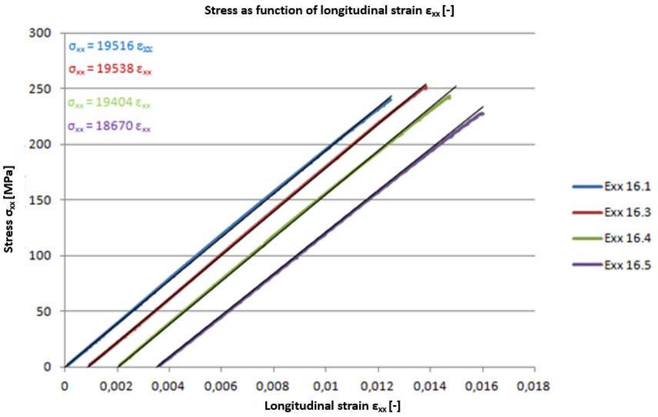

Figure 11 Tension as a function of strain

In fibre direction, brittle failure occures on every specimen in the clamps of the tensile machine. This composite has an average stiffness of 19282MPa.

For the 3D woven multilayer fabrics the majority of the tensile tests are performed in fibre direction. Figure 12 shows the result for the specimens of woven fabric type 1. All the specimens of the different woven fabrics show brittle fracture.

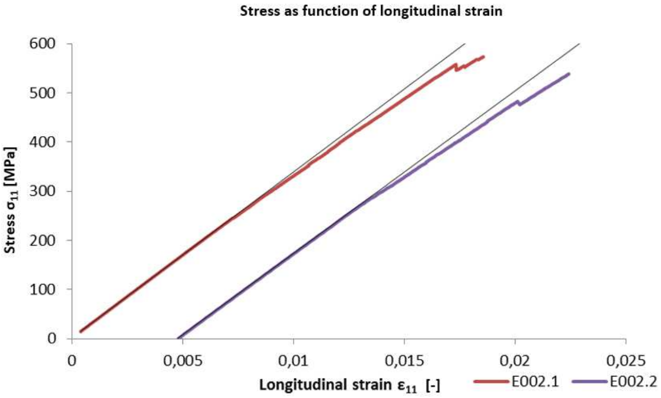

Figure 12 Tension-longitudinal strain relation

The average Young's modulus is 33.84 GPa which is higher than all the other tested woven fabrics. On the graph, it is shown how the curve curls away from the trend line. This is due to damage induced in the composite. The sudden steps in the curve represent large introductions of damage with a drop in stiffness as result. The behaviour between the samples is very similar (note that the curves have been moved over the x-axis to make distinction easier). Figure 13 compares the Poisson's ratio between both samples. The average Poisson's ratio of woven fabric type 1 is 0.31.

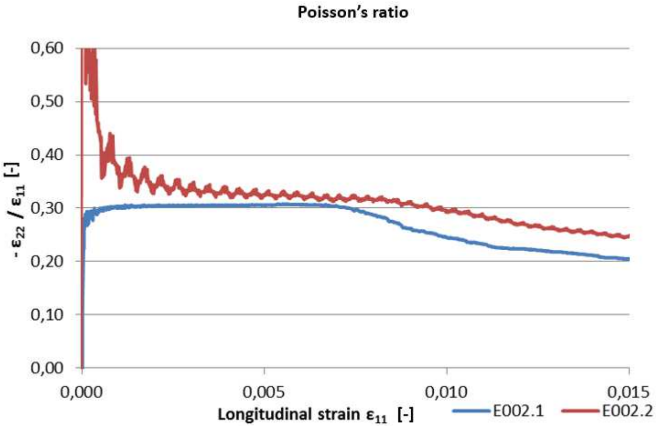

Figure 13 Poisson's ratio

The knitted performs are also tested in fibre direction and transverse on the fibre direction. Example graphs for Young's modulus of a bi-axial reinforced plate with a stacking of $[0/90]_8$ and a fibrevolumefraction of 16.74%, can be found in Figure 14 and Figure 15. Those graphs has been shifted over a respectively 0.005 and 0.002 longitudinal strain.

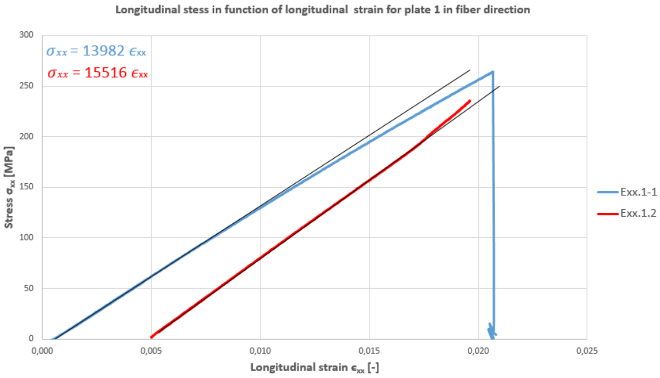

Figure 14 E-modulus in fibre direction

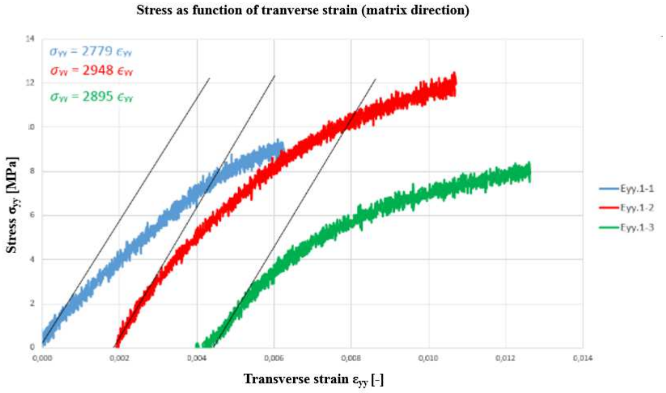

Figure 15 E-modulus in transverse fibre direction

The graphs of Poisson’s ratio can be found in Figure 16 and Figure 17.

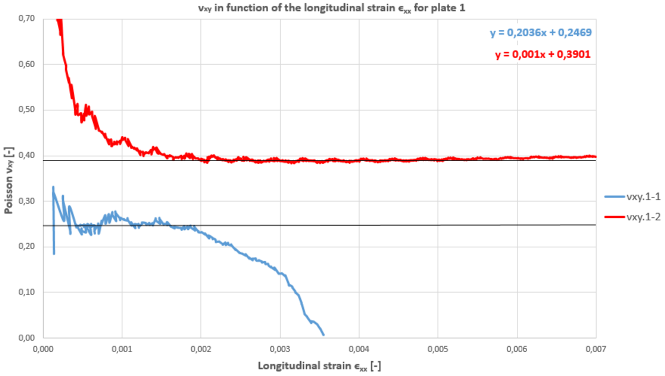

Figure 16 Poisson-coefficient in fibre direction

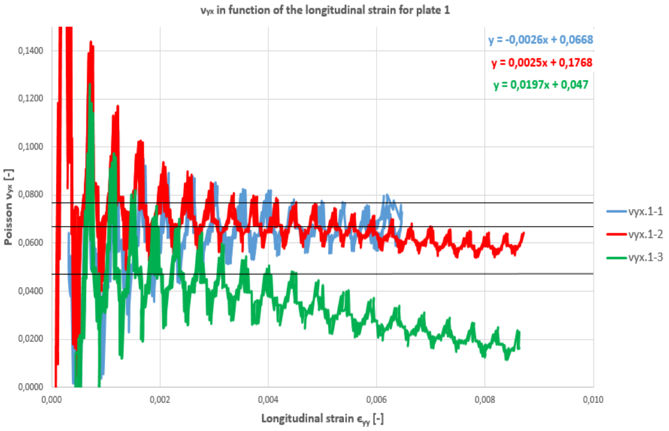

Figure 17 Poisson in transverse fibre direction

Graphs like these are made for all the tested plates and are compared to each other.

Both the bi-axial reinforcement and the way of knitting have no influence on the E_{11} value but the fibrevolumefraction does. For it E_{22} can be derived that the bi-axial reinforcement plays a vital role and increases E_{22} drastically. The fibrevolumefraction, however, has only a small influence on E_{22}.

Determination of the Poisson’s ratio resulted in a high scatter between different parts from the same plate. Therefore, conducting a conclusion based on those values is dangerous and not appropriate.

This high scatter is because of the not optimal conversion process to go from knitted fabric to composite. In production, the knitted fabric should be stretched in order to minimalize scatter.

4 CONCLUSIONS

In this study textile structures are used to improve the impregnation of fibre reinforced thermoplastics (FRTP). Due to the high viscosity of thermoplastics is not that straight forward to get a good impregnation or the apply the methods for the production of thermoset composites. Textile structures, as woven of knitted fabrics, can lead to a better impregnation as the thermoplastic matrix is already in the fabrics so the flow distance of the matrix is reduces. Three possible solutions are tested: (i) pultrusion of the reinforcement yarns, (ii) inserting thermoplastic weft yarns in a woven multilayer and (iii) knitting a thermoplastic around straight reinforcement yarns.

With the pultruded reinforcement yarns, the PVC doesn’t impregnate the entire reinforcement fibre. Research can be done to improve the initial impregnation of the reinforcement yarn itself so the path length is even less. For the 3D woven multilayer fabrics, woven fabric displayed in Figure 3, has a higher stiffness and a higher fracture stress of 571.41 MPa than the other woven fabrics. The simplicity of the woven fabric combined with the good results from the tests indicate that there might be some applications worth examining with 3D-woven preforms as starting material.

A bi-axial reinforced knit can be used as a preform in order to make fibre-reinforced thermoplastics. There are however some more challenges to face in order to make it on an industrial level. Especially the conversion process from the knitted fabric to a composite has to be more specifically developed.

All processes show proof of concept but a lot of research has to be done in how to make the best composite plate out of these textile structures. A combination of the different approaches is also possible as the pultruded yarn can be used in the multilayer fabric in both warp and weft direction

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