INDUSTRIAL WOVEN NON-CRIMP MULTILAYER FABRICS FOR BETTER IMPACT PROPERTIES

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Abstract

The advantages of 3D interlock fabric composites are known to lie mainly in the increased impact resistance and reduced crack propagation. On the other hand, in-plane properties like modulus, strength and fatigue are reduced by the increased amount of yarn crimp in 3D fabrics. Other disadvantages of 3D interlock weaves are poor impregnation performance and low production speeds. In this research project "Multi-NonCrimp", it is shown that multilayer 3D interlock weaves with minimal warp and weft crimp can be produced on full width weaving looms with much greater production speed than conventional 3D weaving. Weaves with different warp, weft and pile yarn densities are impregnated and mechanically characterized by 3-point flexural and bending after impact tests. Results show good impact resistance, but limited bending strength due to incomplete impregnation. Further work will be carried out to optimize weaving pattern and impregnation methods for 3D textile reinforced composites.

1. Introduction

The use of fibre reinforced composites is necessary in lightweight constructions. Due to their great mechanical properties and low density of the materials, composites find their way into more and more application fields. Furthermore, corrosion resistance, impact resistance and other specific performances are advantages of this technology. The most common type of composites in the market is glass fibre reinforced thermosets. The textiles exist in various forms of textile architecture. This can be for instance: nonwoven, woven fabric or noncrimp fabric (NCF). Normally, a composite material consists of multiple layers of fabric, a so-called laminate. In NCF reinforced composites, the fibres are not crimped and have substantial in-plane orientation. This leads to very high in-plane mechanical properties. The fibres in woven fabrics have and out-of-plane orientation (crimp). This effect reduces the in-plane mechanical properties in a composite. However, the interlocking (weaving) of the different yarns increases the resistance to delamination and thus the resistance to impact. Yet, the composites consisting of multiple layers of 2D weaves remain vulnerable to impacts due to the delamination between the separate fabric layers [9].

3D woven fabrics composite parts show significant advantages compared to 2D textile composites. Different types of 3D weaves exist. In figure 1 an overview of these different types is given, as was summarized by Gloy, Neumann, Wendland, Stypa and Gries (2010).

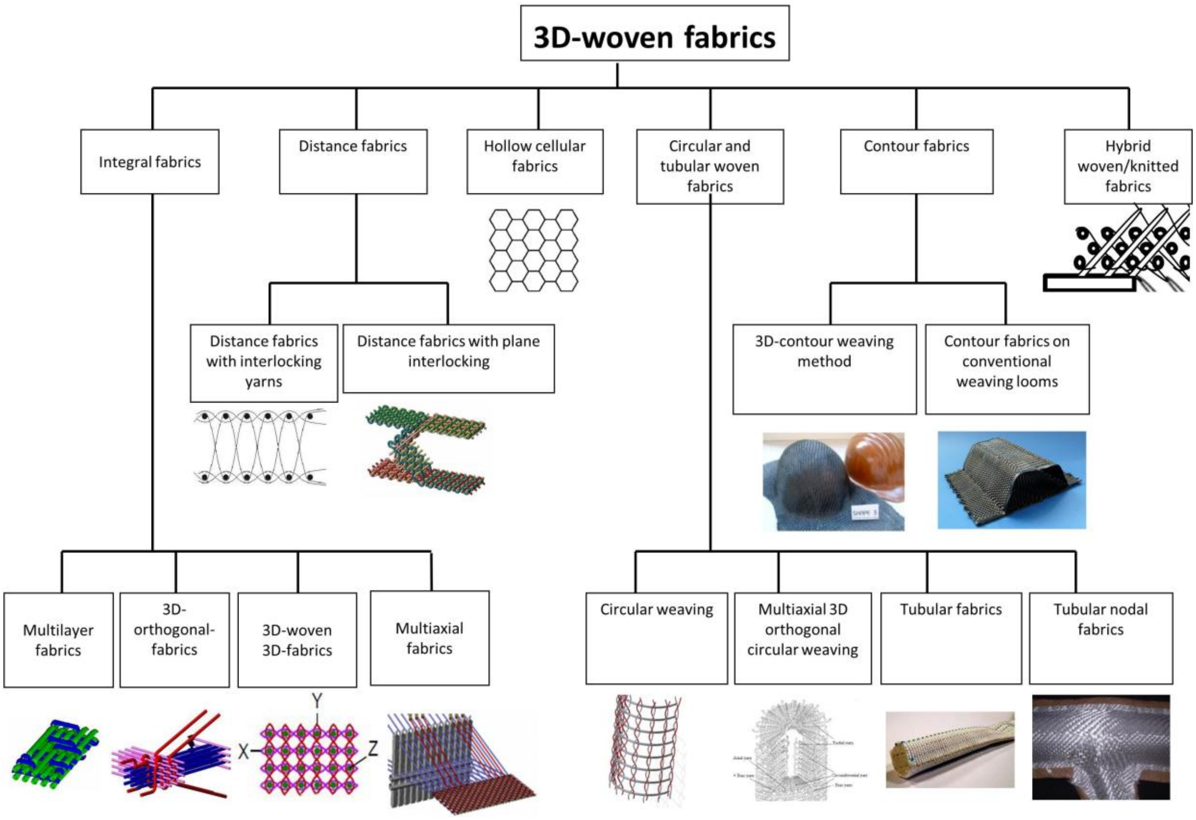

Figure 1. Overview of different types of 3D woven fabrics [4].

The most interesting opportunity to replace 2D fabrics in large and thick parts is a 3D multilayer fabric with interlocking weaves. In this case, several layers of fabric are connected by interlock (or pile) yarns. There exist 3 types of yarn insertions regarding the 3D fabric architecture:

1. Warp yarns that stay within one layer of fabric
2. Warp yarns that interlock different layers: interlock yarns or pile yarns
3. Weft yarns that are inserted during weaving and always stay within one layer

There are two ways of inserting the interlock yarns. The pile yarn can go straight up and down (orthogonal interlock), or at an angle (angle interlock). Using the angle interlock, the pile yarns can connect different layers ("layer-to-layer") or go through the whole fabric ("through-the-thickness"). In figure 2 the main differences between conventional 2D weaving and 3D interlock weaving is shown.

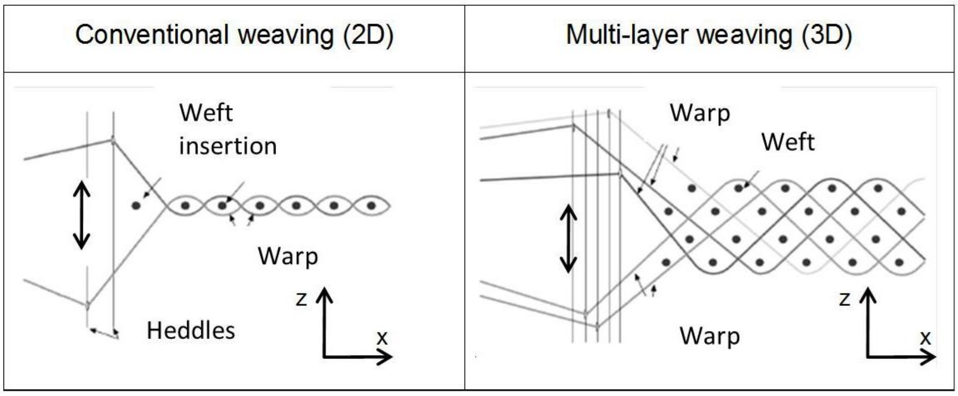

Figure 2. Conventional (2D) weaving (left) compared to 3D weaving (right). In the figure on the right, all warp yarns are *through-the-thickness interlock* yarns [6].

3D woven fabrics have the main advantage in an increased crack propagation and impact resistance compared to 2D fabrics. Due to high amounts of fibres in out-of-plane directions (mainly the interlock yarns), the in-plane mechanical properties on the other hand, are typically lower than in 2D fabric composites. Different studies investigated the properties of 3D textiles regarding the influence of the architecture, like: Brandt, Drechsler and Arendts (1996); Chen, Spola, Paya and Mollst (1999); Gu and Zhili (2002). The portion of pile yarn increases interlaminar shear strength (as depicted in figure 3 left), but decreases in-plane modulus and strength (see figure 3 right) (Soden and Weissenbach 1999). To minimise the loss of in-plane properties, Multilayer *noncrimp* 3D woven fabrics have been developed. These fabrics are essentially 0/90 noncrimp fabrics with multiple layers, connected by the pile yarns during the 3D weaving process (see figure 4).

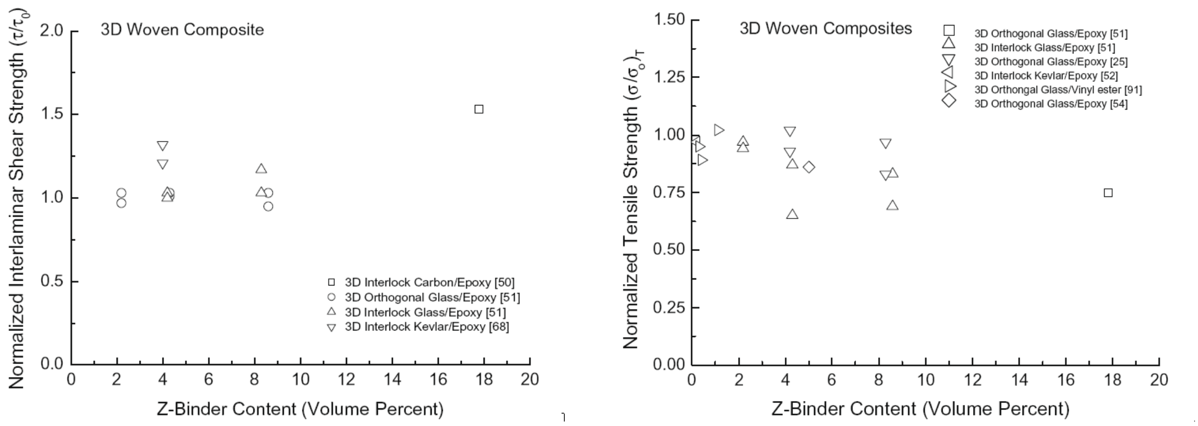

Figure 3. Increase in interlaminar shear strength with increasing amount of pile yarn (left), Decrease in tensile strength due to increased out-of-plane fibre content (right) [8].

Various multilayer noncrimp 3D textiles for composite reinforcement exist on the market, while several companies such as 3Tex, Cary (USA) or Biteam AB, Bromma (Sweden) are focused on the production of the same. However, these 3D textiles are produced as narrow fabrics (max. 60 cm width) and at low speeds (20 – 60 tpm). This dimensioning limits actual applications to specific (smaller) parts in aerospace industry, where impact resistance and crack propagation resistance are of prime importance.

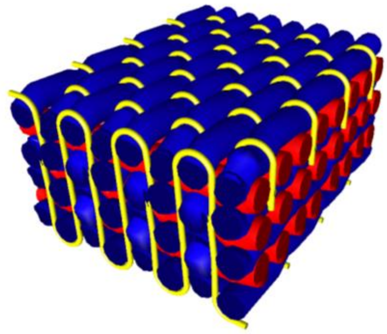

Figure 4. Multilayer 3D interlock weave with the weft yarns in blue, the single layer warp yarns in red and the interlock yarns (through-the-thickness) in yellow [9].

This research further optimizes a technique for 3D weaving on a modified face-to-face multirapier loom, traditionally used for velvet or carpet weaving (De Clercq, et al. 2010). These multirapier looms produce textiles between 1.3 m and 5 m width (depending on type and application). The higher width is a huge advantage in terms of production efficiency when comparing to currently available 3D fabrics [9].

The research presented in this paper is conducted in the Eranet Era-SME project "Multi-noncrimp", with 3 industrial partners: VDS Weaving, 3D Weaving, Novacom and 2 R&D institutions: Centexbel (Gent, Belgium) and ITA of RWTH Aachen University.

2. Multirapier 3D weaving

Traditional multirapier weaving is used to make velvet or carpets. In this case, two layers of woven fabric are connected by pile yarns. Compared to the standard weaving process, multiple weft insertions (hence the name *multirapier*) and multiple warp beams are used. One warp beam is used for the interlock yarns and two warp beams for the warp layers. In standard carpet or velvet weaving, the pile yarns are cut prior to rolling up the fabric in order to produce two fabrics (see figure 5). Essentially, if the cutting process step is skipped, a 3D spacer fabric could be produced. In order to make 3D multilayer fabrics, the space between the top and bottom of the fabric is also filled up with woven layers. To make this possible on a standard multirapier loom, some modifications have to be made (De Clercq et al. 2010).

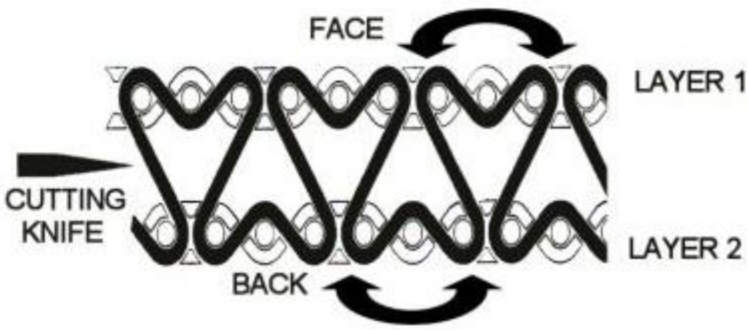

Figure 5. Schematic production of woven velvet with the cutting step [3].

3. Materials and methods

Materials

Glass fibres with 136 tex are used on the warp beam. The weft yarns which are used are 1200 tex with SE3030 sizing from 3B fibreglass (Belgium) and interlock yarns are 68 tex glass fibre. This combination creates quasi-unidirectional composites with a large fraction of the fibres in weft direction. 3D interlock fabrics were made in various constructions with the multirapier technique. In previous research the weft density was varied from 3 yarns/cm to 5 yarns/cm and the amount of weft layers from 4 to 6. In this study, a fabric with 5 layers of warp yarns and 6 layers of weft yarns is produced. A composite plate was produced from the textile using a resin infusion technique and room temperature curing epoxy resin. Compared to the previous conducted research results, the infusion process was optimized.

Microscopy

Cross-sections of consolidated composite plate were made and investigated to view the internal structure and impregnation of the material using both optical microscopy and SEM.

Mechanical testing

3-point bending tests were performed on composites samples according to ISO 14125. Bending after impact was done on the EN 6038 norm for barely visual impact. All impacted were conducted with energy of 0.981 J. ISO 14125 was used for bending strength. Barely visual impact damage is defined as an indentation below 0.3 mm and no visual fibre breakage on the composite surface.

Fibre volume fraction

The fibre volume fraction was determined via two methods. On the one hand, Thermogravimetric Analysis (TGA) was conducted. On the other hand, fibre burn off, following the standard ASTM D2584-02, was performed as comparison to the TGA method.

4. Results

Mechanical

3-point bending tests on samples are shown in figure 6. As expected, strength in the warp direction – perpendicular to the 1200 tex yarns – is much lower. In comparison to the previous research results, the results obtained in this study are depicted. 6 layers in weft direction and 5 yarns/cm in warp direction are examined regarding the improved resin infusion process. The improved resin infusion process was conducted using a resin infusion vacuum bagging technique with a uniformly distributed resin delivery device on the one side and a uniformly distributed vacuum sucking device on the other side of the fabric. Results show an increase of the mechanical properties of the composite of about 35 % in weft direction and more than 60 % in warp direction.

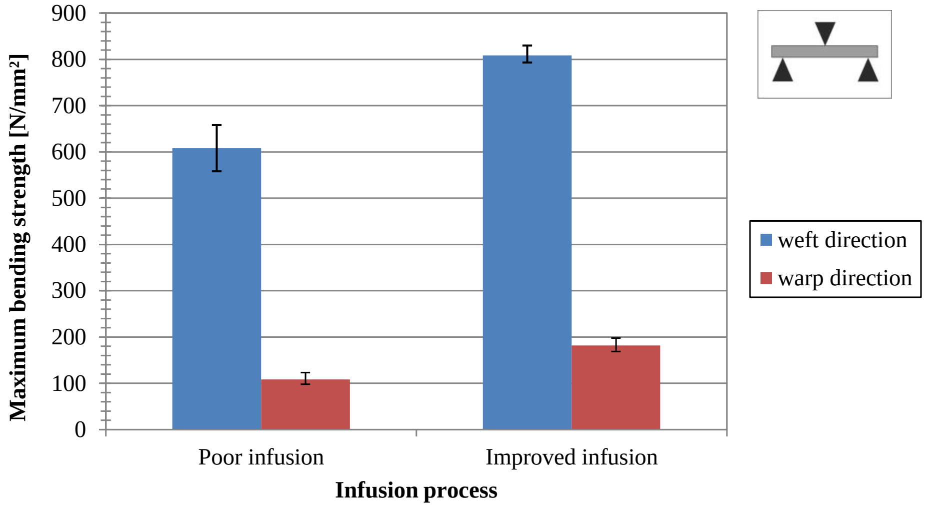

Figure 6. Bending strength in weft and warp direction for 6 layers in weft direction and 5 yarns/cm warp direction; Comparison of the "old" and "improved" infusion process.

Results of bending tests after impact with "barely visual damage" are shown in figure 7. As expected, the mechanical properties are decreasing. In weft direction the average bending strength is decreased by about 24 %. In warp direction decrease of 17 % can be observed. The statistical spread is perceivably, whereas the standard deviation for the results "bending after impact" in weft direction is 182.42 [N/mm²].

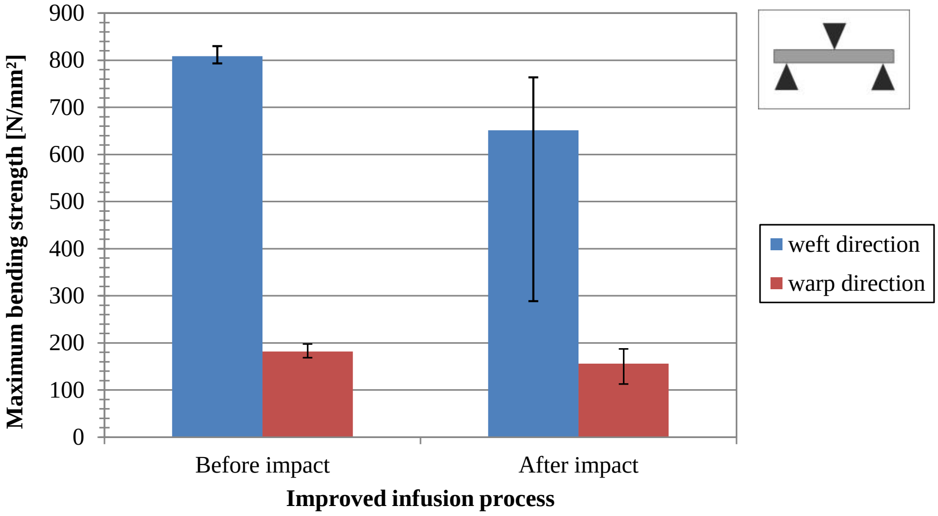

Figure 7. Results of bending after impact test compared to before impact. Focus on the improved infusion process.

Fibre volume fraction

The fibre volume fraction was calculated by using two different methods. TGA determines an average value of 66.25 % fibre content. Since TGA is only possible on very small samples, the fibre burn off method is also conducted. This method generally gives a more representative value and the average value determined by this test is 64.31 %.

Microscopy

Microscopy of the fabric which was produced by the improved resin infusion process is shown in figure 8. Cross-section shows no air pockets between yarns and no intra-yarn voids.

Figure 8. Optical microscopy image of the composite cross-section.

Compared to the infusion process in the previous trials, almost no trapped air can be found in the composite. In figure 9 one example of a composite made with the previous infusion process is shown. The improvement leads to higher mechanical properties and no air pockets.

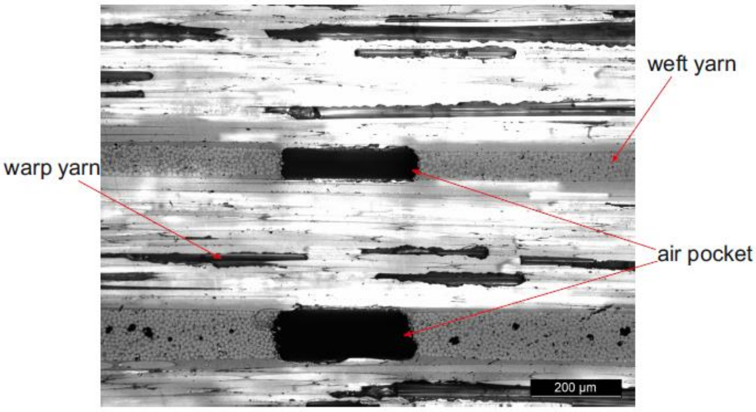

Figure 9. Microscopy image of the cross section of a composite produced with the previous ("poor") infusion method.

5. Conclusion

3D interlock fabrics which are used for reinforced composites can reach high mechanical properties in in-plane direction and furthermore high impact resistance and excellent productivity. In this study, one fabric produced with the improved resin infusion process was compared to the same fabric in previous studies. Due to the improved resin infusion process, the appearance of trapped air inside the composite could have been avoided. Thus, higher mechanical properties could be reached. The bending strength before impact could be increased by more than 60 % in the warp direction. Microscopy images showed large improvement in the resin infusion. However, there is still development in the fabrication of the multilayer fabrics, especially the investigation of different weaves and amount of layers.

Furthermore, investigations of the permeability need to be conducted to acquire knowledge of how the different weaves influence the resin infusion process.

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