

2D net shape weaving for cost effective manufacture of textile reinforced composites

D M P Vo, M Kern, G Hoffmann and C Cherif

Institute of Textile Machinery and High Performance Material Technology (ITM)
TU Dresden, 01062 Dresden, Germany

duy.vo@tu-dresden.de

Abstract. Despite significant weight and performance advantages over metal parts, the today's demand for fibre-reinforced polymer composites (FRPC) has been limited mainly by their large manufacturing cost. The combination of dry textile preforms and low-cost consolidation processes such as resin transfer molding (RTM) has been appointed as a promising approach to low-cost FRPC manufacture. At the current state of the art, tooling and impregnation technology is well understood whereas preform fabrication technology has not been developed effectively. This paper presents an advanced 2D net shape weaving technology developed with the aim to establish a more cost effective system for the manufacture of dry textile preforms for FRPC. 2D net shape weaving is developed based on open reed weave (ORW) technology and enables the manufacture of 2D contoured woven fabrics with firm edge, so that oversize cutting and hand trimming after molding are no longer required. The introduction of 2D net shape woven fabrics helps to reduce material waste, cycle time and preform manufacturing cost significantly. Furthermore, higher grade of automation in preform fabrication can be achieved.

1. Introduction

The use of fiber-reinforced polymer composites (FRPC) in structural components has been being attractive to many industry sectors for decades due to their high strength-to-weight and stiffness-to-weight ratio as well as high resistance to environmental degradation, which potentially lead to both energy and economic benefits over metal parts [1]. In addition, mechanical properties of FRPC can be optimized for a specific application by tailoring material content as well as orientation of reinforcing fibers in the composite. These advantages, however, can only be provided with very large manufacturing cost premiums at the present. This has been restricted the use of FRPC primarily in relatively low-volume and niche applications such as aerospace or luxury vehicles.

In order to support the widespread adoption of these advanced materials, technology advancements are demanded that enable cost-effective manufacture of FRPC for high-volume applications. At the present, utilizing dry textile reinforcement preforms in combination with low-cost consolidation processes such as resin transfer molding (RTM) or vacuum-assisted resin transfer molding (VARTM) is considered as the most effective manufacturing pathways to achieve low-cost FRPC [3]. In most cases, 2D woven fabrics made of high performance fibres with constant width are used that need to be cut into tailored shaped pieces before being stacked and joined into a matched preforming tool with specific shape to meet mechanical and structural requirements. As cut fabric edges are unstable, oversize patterning, skilled hand labor as well as trimming after consolidating are required which



consequently make the fabrication of preforms and composites expensive. As shown in Figure 1, at least 50% of FRPC total manufacturing cost is accounted for by preforms fabricating [5].

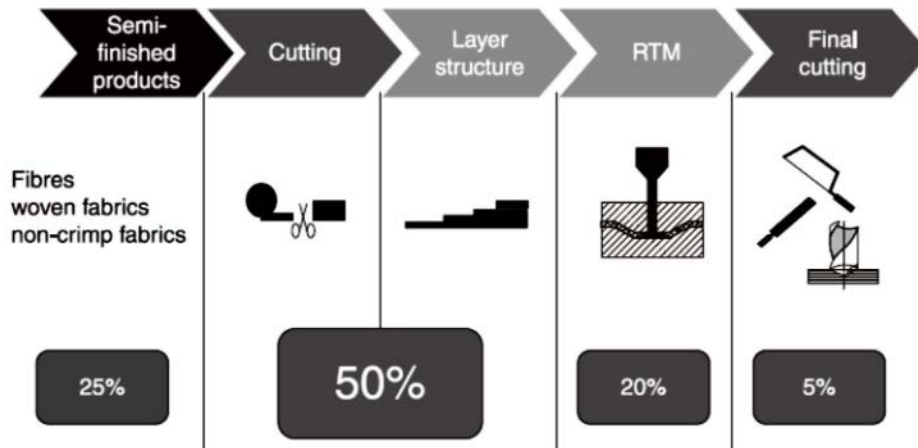


Figure 1. Cost distribution in manufacturing preform for FRPC [5].

To achieve a more cost-effective system for FRPC manufacturing, optimization advances in textile preform fabrication are needed. A promising approach is the implementation of 2D net shape woven fabrics. In contrast to a conventional woven fabric whose width remains constant along the entire length, a 2D net shape fabric is produced with variable width conforming to a tailored contour so that the desired fabric shape for preforming can be achieved solely out of weaving process. Cutting is therefore simplified or even eliminated. Process count, material scrap, tooling and workforce will be reduced which helps to cut down the expensive preform manufacturing cost. Furthermore, a higher grade of automation in preform fabrication can be achieved.

Recently, innovative structure concepts of 2D woven fabrics with tailored contour have been developed and patented by ITM [6]. The described structures show a high potential to be applied in FRPC, however, technical means for their realization is currently missing. With the aim to establish a more cost-effective system for the manufacture of dry textile preforms for FRPC, advanced 2D net shape weaving technology has been developed. On the basis of Open Reed Weave (ORW) technology of Lindauer Dornier GmbH, Lindau, Germany, technological and constructive solutions have been carried out to enable the fabrication of 2D net shape woven fabrics on a broad rapier loom. 2D net shape weaving has been implemented at ITM. A wide variety of 2D net shape woven contours can be achieved with high geometric precision. Resulting structures show advanced characteristics that can bring both performance and cost advantages to composites fabrication such as globally uniform structural parameters and sufficient edge stability along desired contour. The development and achievements of advanced 2D net shape weaving are presented in this paper.

2. Technical background of 2D net shape weaving

A weaving technology that has great potential to fabricate 2D net shape woven fabrics for being used in FRPC is the Open Reed Weave (ORW) technology. Beside the conventional working elements such as warp let-off, shafts, rapiers and fabric take-up a typical ORW machine is featured with a reed opened upwards and a number of thread guides made into needle form. The needles are arranged in arrays, each array is coupled with a linear motor to form a sideward movable system. The shaft on which one or more sideward movable systems are mounted is called special shaft and installed between the open reed and other conventional shafts. Warp yarns guided by the needles are fed separately and therefore called extra warp yarns. During shedding, the special shaft is lifted or lowered according to a given weave pattern while the linear motor is controlled to move along weft direction. This mechanism allows extra warp yarns to be integrated in the fabric in a way that one interlacing point is horizontally offset from another [7].



Figure 2. Rapier weaving machine with ORW function PTS 4/SOD.

At ITM, the rapier weaving machine with ORW function PTS 4/SOD from Lindauer Dornier GmbH, Lindau, Germany is employed to manufacture 2D net shape woven structures (Figure 2). Two sideward movable systems are mounted on the special shaft. As each linear motor can be controlled independently, it is possible to generate woven structures with two sets of integrated extra warp yarns, each has separate pathway. During weaving, each set of extra warp yarns can be shifted 5 or 10 mm between two main shaft rotations and 300 mm in total. 2D net shape weaving have been developed and implemented on the basis of ORW. This is presented in the following paragraphs.

3. Realisation of 2D net shape weaving

3.1. Structure concept and manufacturing method

The concept of 2D net shape weaving using ORW technology is to integrate extra warp yarns made of fine material in a standard woven fabric in a way that their pathway conforms to the contour of desired fabric shape. The schematic illustration of such structure can be seen in Figure 3. The integrated extra warp yarns serve on one side as a marked outline along which the fabric will be cut after weaving to achieve the desired shape and on the other hand as means of stabilizer which keeps the cut edge from fraying. In this way, resulting fabric cut piece can be processed easily during preform fabrication without requiring oversize patterning and subsequent hand trimming.

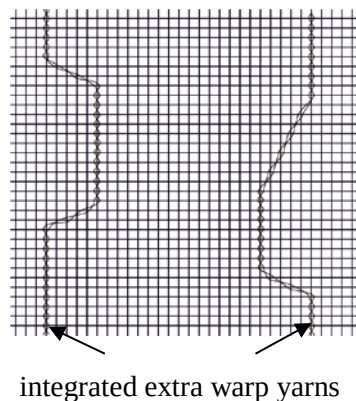


Figure 3. Concept of 2D woven fabric with integrated warp yarns in tailored contour.

2D net shape weaving TV1 can be implemented on a standard existing ORW weaving machine. A standard fabric with constant width is woven using conventional shafts and works as a base structure. Sideward movable systems in the special shaft are used to guide the extra warp yarns. The cut edge stabilizing function of extra warp yarns is realized in form of leno selvedge. By controlling the lifting plan of the special shaft in combination with appropriated sideward movements, a leno selvedge in accordance to a desired contour can be generated.

3.2. Configuring and realizing leno selvedge using ORW technology

The ORW technology offers the possibility to generate a great variety of leno configurations. In 2D net shape weaving by means of integrated leno selvedge, the most essential criteria are resulting cut edge stability and contour design flexibility. In order to understand the influence of different leno configurations on the behavior of leno selvedge in respect of these characteristics and thereout determine appropriated configurations to be applied in 2D net shape weaving, various leno weaves have been designed, realized and characterized.

At ITM, woven fabrics with integrated leno selvedge have been produced on the ORW rapier weaving machine PTS 4/SOD. Base fabric was manufactured in plain weave from glass roving 1200 tex in both warp and weft systems. Warp density is 4 yarns/cm and weft density is 3,5 yarns/cm. Warp system is fed from a warp beam to achieve an even warp tension across the fabric width. Due to varied consumption during selvedge formation, extra warp yarns (in the following will be mentioned as leno yarns) are delivered separately from bobbins. To minimize structural and optical variation in resulting 2D net shape structure, fine filament yarns are used to generate leno selvedge. Samples have been made with textured polyester multifilament 167 dtex. In order to have a standard basic for the characterization and comparison various leno configurations, straight selvedge were first applied for design and preparation of testing samples. The production of 2D net shape woven fabric with integrated leno selvedge and selected resulting structures are shown in Figure 4. 2D woven fabrics produced with one integrated leno system (Figure 4b) and two leno systems which are reversely integrated (Figure 4c) can be observed.

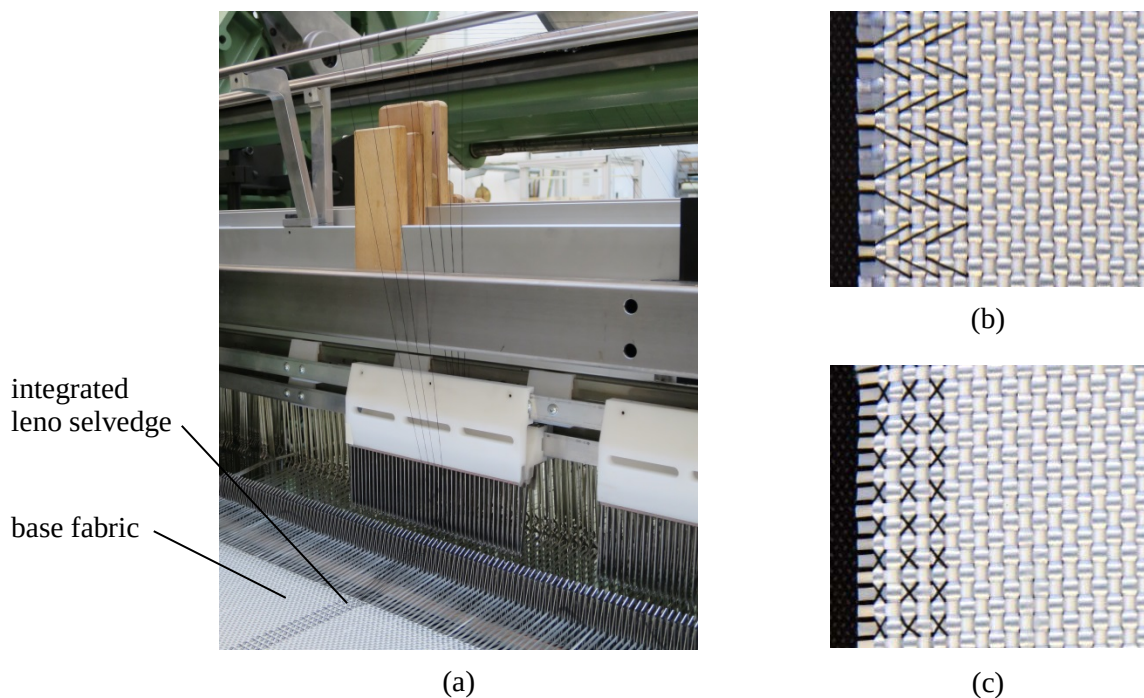


Figure 4. Production of 2D woven fabric with integrated leno selvedge (a) and resulting structures.

3.3. Characterizing leno selvedge

As mentioned above, resulting 2D woven fabrics with integrated leno selvedge in various leno configurations have been characterized in terms of resulting cut edge stability and design flexibility. Cut edge stability is determined based on the pullout strength of the most outer warp yarn. A special pull out test has been conducted at ITM. Samples with and without selvedge were tested and compared to each other in order to verify the effect of integrated leno selvedge on the cut edge stability. Generally, cut edge stability of 2D woven fabrics is improved with integrated leno selvedge. Pullout strength of the most outer warp yarn varies depending upon applied leno configuration. An over 50 N force is needed to pull the most outer warp yarn from a woven structure having the most stable cut edge while there is nearly no force required for woven structure without integrated leno selvedge.

The contour design flexibility of a leno configuration is determined by the minimum value of the slope of diagonal selvedge that can be realized. The more gentle diagonal selvedge that can be realized, the wider variety of contours can be generated. Analyses have shown that obtainable minimal slope of diagonally integrated leno selvedge and therefore the contour design flexibility depends greatly upon applied leno configuration. Further influencing factors are technological capability of employed ORW weaving machine and weave parameters. At ITM, diagonal leno selvedge that form a 20° angle to weft yarns can be realized on a base woven fabric described above.

3.4. Manufacturing 2D net shape woven fabrics with integrated leno selvedge in tailored contour

Based on the above evaluation the most optimal leno configuration to be applied in manufacturing tailored contours on a 2D woven fabric by means of integrated leno selvedge has been determined. This leno configuration offers a high design flexibility and provides the cut edge with high stability. As can be seen in Figure 5, a wide range of fabric shapes, from patterns with combined slope angles to car fender with freeform curve, can be realized with integrated leno selvedge. The resulting patterns can be cut from the base woven fabric with precise dimension and are ready for preform fabrication. Structural parameters (yarn density, gsm) remain even overall in resulting structures. Contour edge is stabilized that prevents yarn displacement and material lost when draping.

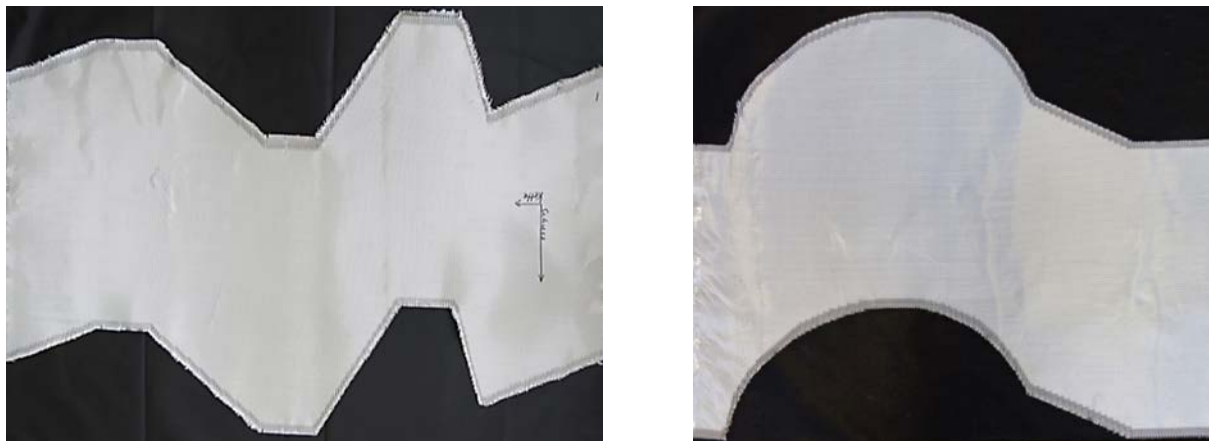


Figure 5. 2D net shape woven fabrics with integrated leno selvedge in various tailored contours.

4. Conclusion

Advanced 2D net shape weaving has been developed on the basis of ORW technology. Using available ORW machine, a standard woven fabric with integrated leno selvedge in tailored contour can be fabricated. Leno selvedge made of fine multifilament yarn marks the desired fabric shape and keeps the cut fabric pieces from fraying. A variety of leno weave patterns are developed and evaluated in terms of cut edge stability and contour design flexibility. Cut edges with integrated leno selvedge show significant stability improvement compared to that without selvedge. Freeform leno selvedge

that has a slope angle between 20° and 90° relative to weft direction can be realized in a woven fabric made of glass fiber roving 1200 tex.

The successful development of 2D net shape weaving using ORW technology helps to establish a more cost effective system for the manufacture of dry textile preforms for FRPC. 2D contoured woven fabrics with firm edge can be obtained by weaving so that oversize cutting and hand trimming after moulding are no longer required. In this way material scrap, cycle time and preform manufacturing cost can be reduced significantly. Furthermore, higher grade of automation in preform fabrication can be achieved.

Acknowledgement

This work presents selected results of the IGF research projects 18583BR of the Forschungsvereinigung Forschungskuratorium Textil e. V., Reinhardtstr. 12-14, 10117 Berlin and is funded through the AIF within the program for supporting the „Industrielle Gemeinschaftsforschung (IGF)“ from funds of the Federal Ministry of Economics and Technology (BMWi) by a resolution of the German Bundestag.

References

- [1] Mills A 2001 *Composites A* **32** 955–62
- [2] Bayern Innovativ Gesellschaft für Innovation und Wissenstransfer mbH 2013 *Jahresbericht 2012* (Nürnberg)
- [3] Lässig A, Eisenhut M, Mathias A, Schulte R T, Peters F, Kühmann T, Waldmann T and Begemann W 2012 *Serienproduktion von Hochfesten Faserverbundbauteilen – Perspektiven für den Deutschen Maschinen- und Anlagenbau* (Roland Berger Strategy Consultants)
- [4] Campbell F C 2004 *Manufacturing Processes for Advanced Composites* (Oxford: Elsevier Advanced Technology) pp 303–330
- [5] Sköck-Hartmann B and Gries T 2011 Automotive applications of non-crimp fabric composites *Non-crimp Fabric Composites – Manufacturing, properties and applications* ed S V Lomov (Cambridge: Woodhead Publishing Limited) chapter 20 pp 461–480
- [6] Cherif C, Hoffmann G and Sennewald C 2015 Gewebe, Verfahren und Vorrichtung zu dessen Herstellung *Patent EP 2 832 906 A1*
- [7] Wahhoud A 2011 *Melliand Textilberichte* **4** 195–7
- [8] Cherif C 2015 *Textile Materials for Lightweight Constructions: Technologies - Methods - Materials - Properties* (Berlin: Springer)