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CONTINUOUS MANUFACTURING OF TAILORED REINFORCEMENTS FOR LIQUID INFUSION PROCESSES BASED ON STITCHING TECHNOLOGIES

C. Weimer , P. Mitschang and M. Neitzel

Institut für Verbundwerkstoffe GmbH, Erwin-Schrödinger-Strasse, Bld. 58,
67663 Kaiserslautern, Germany: weimer@ivw.uni-kl.de

SUMMARY: Providing individually adapted reinforcement structures for Liquid Composite Moulding (LCM), the efficiency of the overall manufacturing process has raised. In the last decade, different approaches towards automated preform-processing have been evaluated. The most crucial issues - such as economic processability and mechanical performance – interfere. While Binder-Preforming techniques, e.g. 'Direct Spray Preforming (P4)", are found to be very useful in parts where mechanical performance requirements are low, highly integrative textile technologies, e.g. 3D-weaving or 3D-braiding, cause problems due to freedom in design and cost. But, focusing on a process suitable for LCM-, a flexible preforming process is needed. Sewing routines adapted from the garment, furniture, shoe and lingerie manufacture have been put into a process chain withthe advantage to produce tailored reinforcement structures (TR process) for semi-structural applications of high quality (e.g. non-wovens or strand mats) as well as structural, even aerospace structures (e.g. woven or non-crimp fabrics) on a flexible basis. The results of this study support the TR-concept in terms of infuseability as well as economical and design issues The proposed idea of continuous manufacture, the so called "Tailored Reinforcements", not only offers the possibility of processing high performance fabrics, but also offers an alternative to the "Direct Preforming", e.g. P4 Preforming. In the later case, the "Tailored Reinforcement" routine also combines cost effective processing with additional high performance structures, and both can easily be brought into process.

KEYWORDS: Preform, RTM, LCM, Stitching, Reinforcement, Through-the-Thickness Stitching

INTRODUCTION

Preforming of fibrous reinforcement structures for manufacturing of fiber reinforced polymer composites (FRPC) is getting more and more into the focus of end-users working within the application areas of FRPC. In particular Liquid Composite Molding (LCM) techniques are gaining from the advancement in preform manufacture. Different approaches to solve the problem of manufacturing multi-layer composites has led to a wide range of different manufacturing routines. Each one of those technologies offers a unique potential. Advancements of these technologies are the realization of tailored fiber orientations within the reinforcement as well as special shapes produced in-situ during the performing step [1].

Looking at cost effective manufacturing of 3D-shaped structures the freedom in fibre-orientation is limited. Standard performing techniques are based on the spray-up of fiber-assemblies [2] and therefore cover only random fiber orientations. 3D-textile approaches are often limited in production rates and flexibility in terms of geometry and fiber orientation. Fig. 1 gives an overview of different performing routes. Compared to these “Direct Prefom Processes (DPP)”, “Multi-Step-Preform-Processing” routines look more diversified. Although different steps have to be incorporated into the preform manufacturing process, these techniques seem to cover many applications. The “performing depth” – the extent to which performing has to be performed – can be adapted to the current application and provides therefore flexibility. There are two ways to solve this problem. One way is to use the Binder-techniques by applying a polymer powder – or a form of adhesive – to form a semi-finished product (e.g. woven fabrics) [3]. The other way is to cut dry fabrics into the desired shape and stitch the individual layers together. This process is called “cut-and-sew” technique [4].

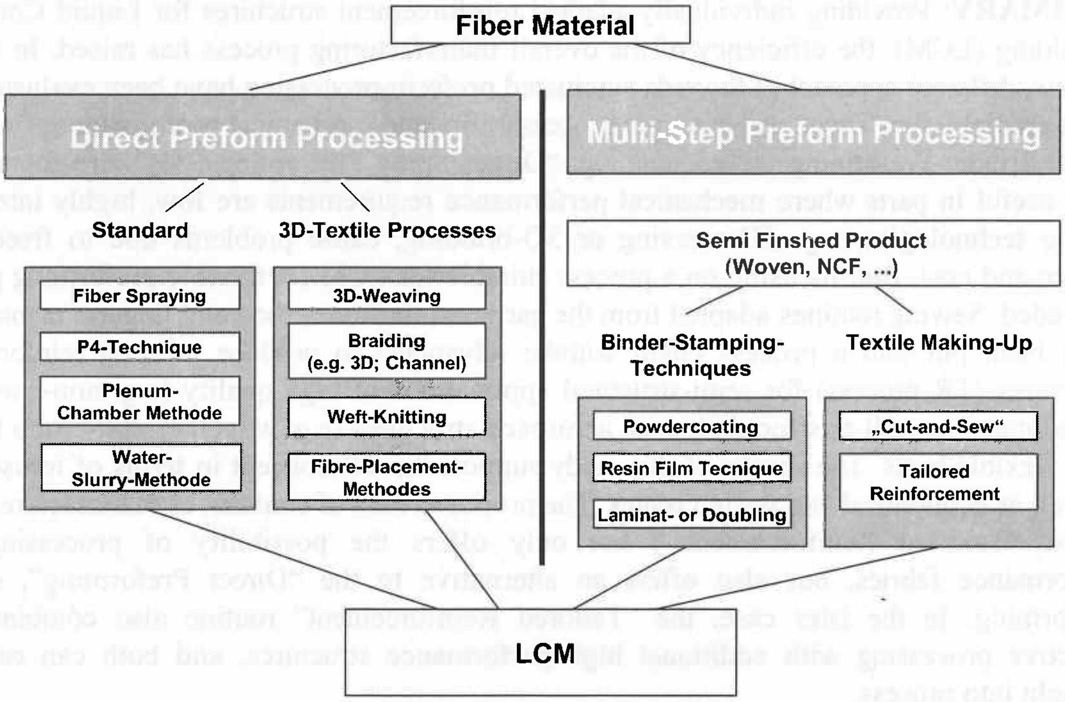

Figure 1 Possible Preforming Techniques for Making-Up LCM-reinforcements

Going the way of introducing more making-up routines from the garment manufacturing business, these individual dry cuts need to be pre-tailored in order to be automatable. This pre-tailoring step is, in terms of further advancement of the complexity of the preform, the most critical element. The “Tailored Reinforcement (TR)” is the basis for on-going preform assembly steps.

To understand the applications of sewing, the stitching process itself is mandatory. However, the seams itself have to be classified first. The differing functions of the seams ask for individual adaptable stitching parameters. These stitching parameters, again, must be differentiated. There are macro-stitching parameters, e.g. stitch length and width or stitch density, but there are also technology driven stitching parameters, e.g. thread tension, pressure-foot height or the steering of the stitch formation process. The following section gives an overview of the different areas in which seams can provide benefit within the preform manufacturing process.

TYPES OF SEAMS

The definition of the various classes of seams describes the difference in the demands imposed on the seams themselves:

Fixing and Positioning Seam

This class describes the preforming of complex structures. Individual layers are fixed in the correct position relative to each other. Where tailored reinforcements with accurate end contours, especially continuous fiber reinforcements are used for FRPCs, allowance must be made for in-plane distortion of the semi-finished goods as well as displacement of layers between the various layers of packages. The threads are intended only as a production aid and ideally should be removed from the textile tailored reinforcement after several more preforming stages. Overlock seams are used for making sub-preforms with accurate end contours and are therefore regarded as fixing and positioning seams for making up accurate individual parts.

Assembly Seam

Seams of this type are especially important for mould loading and the injection process. The structure of the seam of the preform is already determined. Workholders are not usually needed. Assembly seams define the accuracy of the moulded part contour during both sub-preform manufacture and preform assembly. Furthermore they can provide ease of folding and locally adapted fiber volume fraction for accurate moulding.

Joining Seams

These are force-transmitting seams, i.e. structural seams. Their purpose is to transmit forces between various semi-finished goods or layers with tailored reinforcements (e.g., ribs on support structures) or to connect individual part sections. Joining seams should also be used for positioning inserts or to enhance connections of inserts to the entire structure. Joining seams generally penetrate the complete preform and are best made with reinforcing sewing threads.

On-line integration of load elements into the dry fibrous perform during manufacturing is a further step for the advancement of "3D-Tailored Reinforcements". The sewing yarn used in this process serves to transmit the force that is applied to the composite part and, for instance, increases the pullout forces of threaded rods or even prevents delamination within the composite [5].

The 3D-reinforcement structure corresponding to the parts shape, is assembled to a certain extend of integrity. Concerning these steps, the selection of the right machines on one hand and the developing of different threads and process parameters on the other one, have to be looked at in parallel. The finishing of the 3D textile reinforcement for FRP-parts generally requires the use of work-piece holders of correct geometry and guiding elements for positioning the individual parts. Thus, the possible potential in cost reduction via the integration of Preform and RTM is not totally exploited.

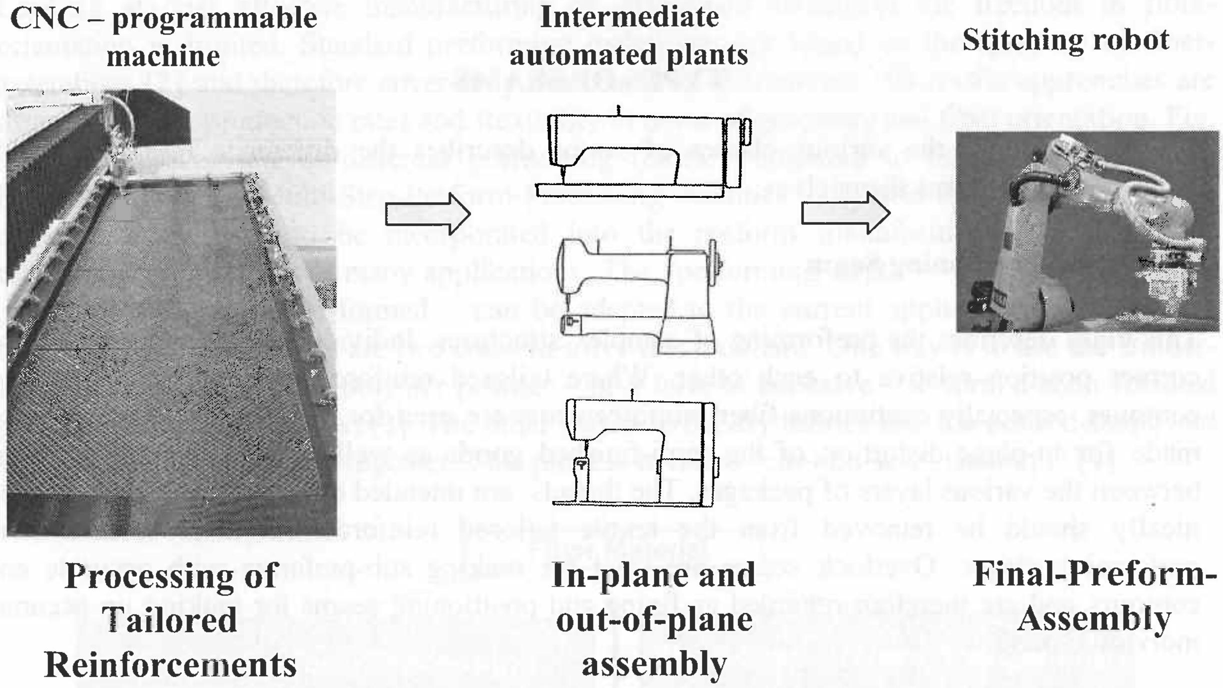

Figure 2 Different steps of performing manufacturing

The different steps of "TR" processing to the final preform require different machine lay-outs. Fig. 2 briefly shows different constructions of sewing plants. For the three main important steps of making-up textile reinforcements;

- Generating handleable TRs,
- Assemble TRs with Standard Machines and
- Applying robot systems for 3D-Stitching,

the classification of the seams brought into the structure is still valid [6].

PREFORM – ENGINEERING

Addressing reproducibility and quality of the stitched preforms, the complete process chain must be embedded in an engineering environment. This approach leads to a continuous transfer of data-sets from the 3D-design to the stitching data. Starting at the 3D-model of a part, which must be designed according to preforming manufacturing issues, 2D datasets need to be generated. Unwinding of 3D-models is currently done using sheet-metal unwinding tools that are incorporated in commercial CAD-software packages. These 2D-datasets are then transferred to a new "Preform-Engineering" Software package via standardized interfaces. According to newly developed "Preform-Engineering" guidelines, the individual "Tailored reinforcements" can be generated. During this step the necessary seams in each reinforcement package are constructed. The attributes, e.g. thread tension, of these seams are assigned.

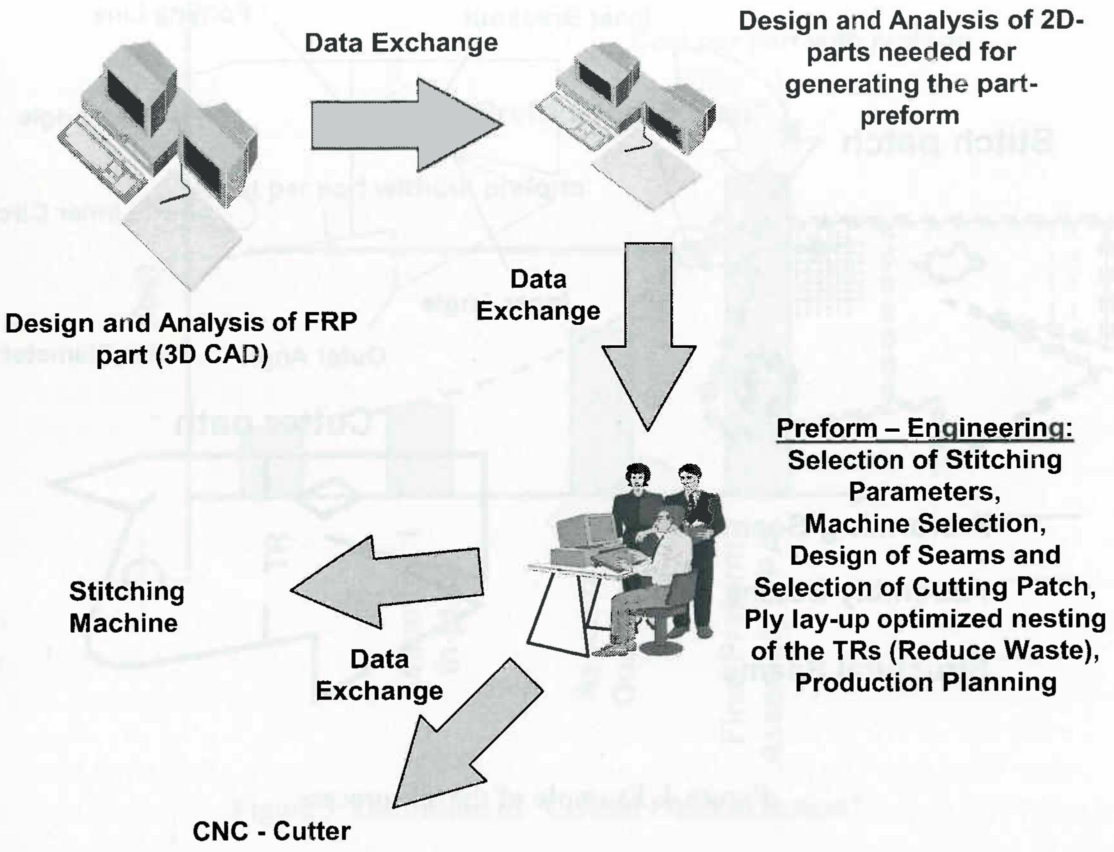

Figure 3 Dataflow in the preforming process

The different seam types described in the previous section require a machine specification that allows to change stitching parameters during the ongoing manufacturing process. Finally, preform-engineering allows the generation of the cutting patch within the "Tailored Reinforcement" including folding cuts. Fig. 3 gives an overview of the dataflow from the 3D-CAD-model to the final data sets for the stitching and cutting plants.

Fig. 4 shows that the stitching, cutting and original shape of the needed part are different. The designed stitch path of a preform is then determined by the desired "shape" tolerance of the reinforcing member. These requirements lead to a certain stitching-length, stitch density etc. Assembly seams and structural seams have to be designed according to guidelines set up by processing requirements or mechanical properties.

The new technology now combines the stitching and the cutting process. The material stack is kept in a special template to prevent warpage that could be caused by material handling between the two manufacturing steps. The cutting follows the tracks of the preforming seams. Double row stitching can thus be considered as beneficial because of the fact that the potential waste can be limited to minimum. One of these double row stitches stays within the part, whereas the other holds the material stack in place so that the complete package can beexploited further on [7].

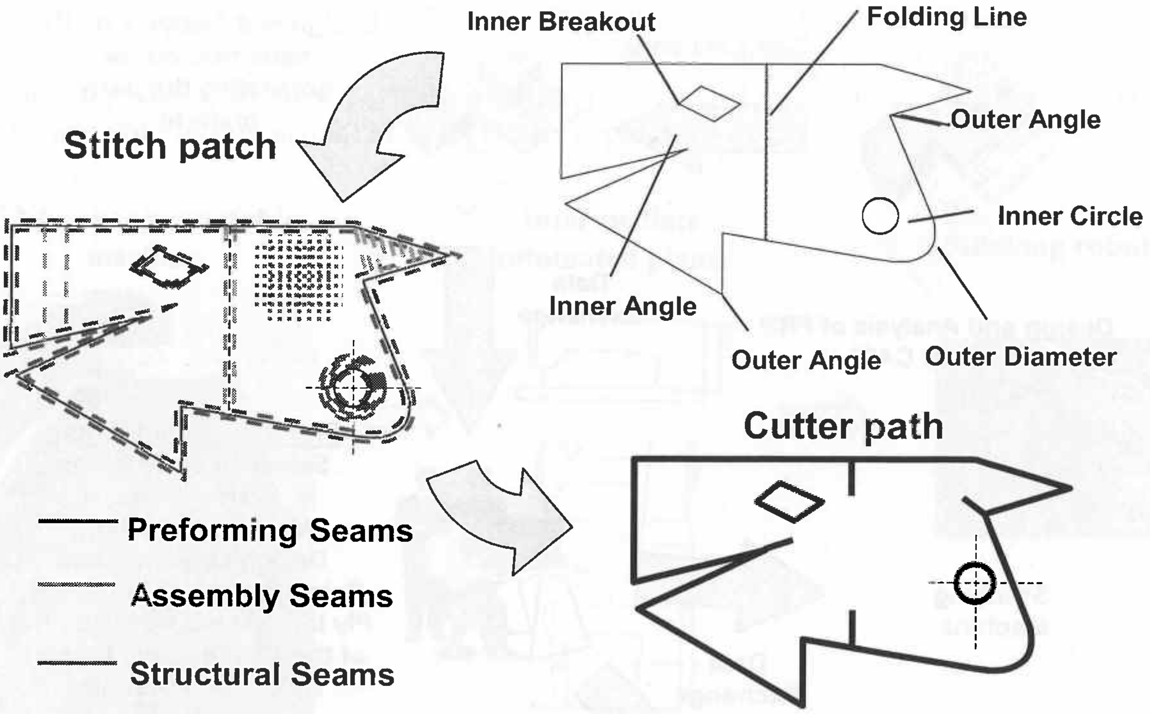

Figure 4 Example of the TR process

ECONOMICAL APPROACH

Following the routines to assemble a complete part-preform more assembly steps are incorporated. These follow-up processes require more specialized machinery. In most of the cases at least one initial in-plane assembly step to mount at least 2 different TRs on top of each other is necessary (Assembly 1; Fig. 5). In most cases, this step can be realized in a highly automated way and thus the cost benefit for the complete LCM-structure comes along with a technological benefit. This assembly step is than followed by different out-of-plane assembly actions (Assembly 2 and Assembly 3). Within these processing actions, the final part shape is generated and thus many part-shape templates are needed. By this means, the cost benefit of "Tailored Preforming" is limited. If the volume of the manufactured parts rises, the economical efficiency rises as well. This is due to the fact that the labour introduced into the preforming leads to a faster production of the LCM-part. Apart from economical issues, preforming often leads to a technological benefit. 3D- or Through-the-thickness-reinforcements can be introduced during all preform assembly steps. These parallel processes add only few costs to the overall preform effort since no additional loops in the making-up of the reinforcement have to be introduced. In the latter cases the "Critical Preform Action" is shifted towards automated 3D-assembly of the preform using for example stitching robots. However, if such systems are introduced into the preform making-up process, additional assembly steps have to been taken over in order to make use of their total productivity. If standard glass-fiber semi-finished products are introduced into this processing routine – e.g. manufacturing of multi-layer packages - the cost benefit of the TR process can be introduced into typical LCM applications – e.g. glass-fiber reinforced UP-resins.

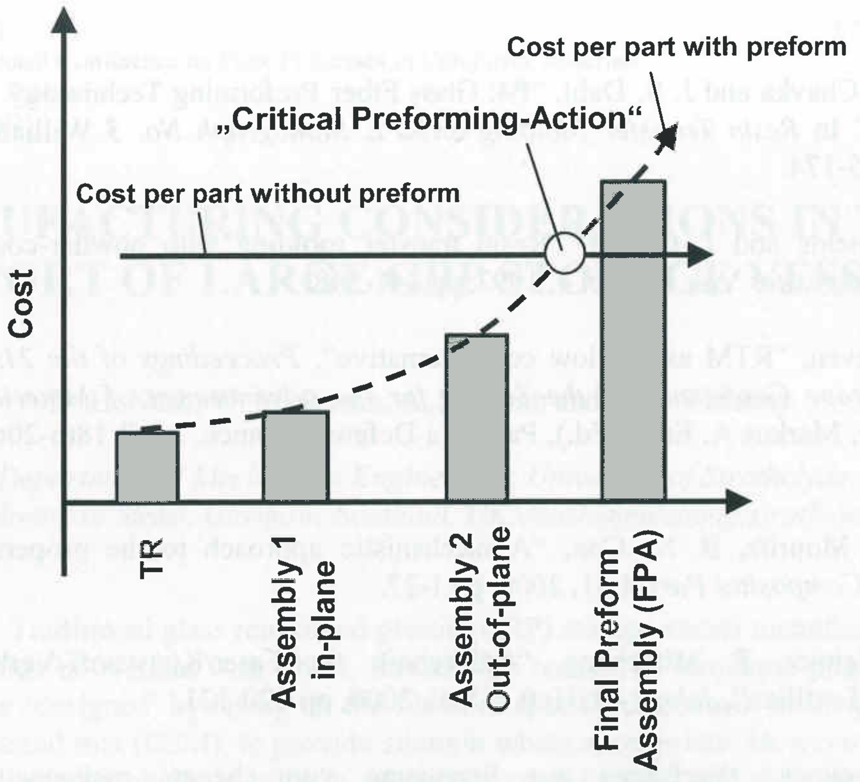

Figure 5 Definition of "Critical Preform Action"

CONCLUSION

A new process chain for making-up dry fibrous reinforcements is introduced. The continous manufacturing of "**Engineered Tailored Reinforcements**" (that is: transferring the stitched fabrics to a CNC-cutter within one frame) is the basis for an adequate assembly of 3D-structures applying sewing routines. The "Preform-Engineering" environment is presented. Based on one dataset, "Quality-Management" can be introduced. Furthermore, the continuous use of the same dataset allows to re-engineer the preform after running the LCM-Flow-simulation. The reason for this is the reproducible and highly accurate manufacturing process. LCM-processes, that are in general a very flexible manufacturing method for FRPC, are advanced by the use of these stitched preforms. The economical benefit is dependant from the selection of the right "Critical Preform Action".

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