Customized Woven Fabrics made of Glass and Carbon Fibres for Industrial Applications

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Abstract

Woven fabrics made of glass and carbon fibres are normally designed based on existing knowledge and as standard products. In this case, the weave pattern, fibre material and weft/warp density are the only characteristics to be considered. Other properties like drapability, form stability in combination with the mechanical properties are not considered though they are vital for the future application. However, a high performance of the application and a low reject rate can only be established by producing a customized fabric. In this research project "CustomWeave", it is shown that based on individual input parameters the weaving machine parameters can be adjusted alike to produce a tailored woven fabric according to part geometry and mechanical requirements. First results show significant dependencies between fabric properties and machine settings. Further work will be carried out to develop an empirical model in which properties like mechanical properties, fibre material, weave and drapability are transformed into weaving machine parameters. The presentation includes recent results of the research project in which the Institut für Textiltechnik (ITA) of RWTH Aachen University, Aachen, Germany and the company Klevers GmbH & Co. KG, Mönchengladbach, Germany collaborate in developing the empirical model and the implementation of a customer guideline to simplify the transformation from customer requirements to the customized woven fabric.

1. Introduction and State of the Art

The market for composite materials like glass (GFRP) and carbon fibre reinforced plastics (CFRP) is continuously increasing in the next years. Small (>1.000 parts) and medium (>10.000 parts) production numbers will have the largest share in the predicted high growth rates. The demand in the US-market is expected to reach 12 billion Dollars by 2020 [1]. The demand for fibre reinforced materials is driven by different user sectors, like transportation (e.g. automotive, aerospace and rail), energy (e.g. wind energy, pipes and vessels), sports and construction. Due to the manifold applications for fibre reinforced plastics (FRP) the requirements for composite materials and therefore the reinforcement textiles vary over a broad range. One of the most common reinforcement textiles are woven fabric due to their good drapability, handling stability and mechanical properties. [1-5]

1.1. Influencing factors of the weaving process on the composite properties

The properties of the fabrics however depend on a wide range of parameters. The performance, costs and appearance of the fabric depend mainly on the fibres or yarns used, the weaving loom and equipment like guiding elements as well as on the process parameters. All woven fabrics consist of

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two rectangular interlacing yarn systems, the warp and the weft yarns. The basic principle of weaving is depicted in Figure 1. [4][5]

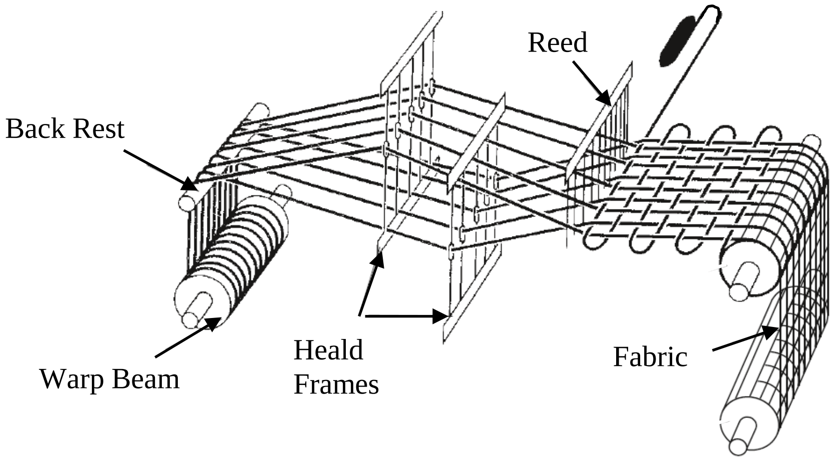

Figure 1: Basic Principle of weaving [6]

The warp yarns can either be stored on a creel or can be wound on a warp beam in a separated process. The parallel yarns are released from the warp beam or creel and guided across the back rest. The back rest and warp let-off should ensure the proper tension of the warp yarns. The warp yarn tension is an essential parameter for the weaving process and has a high influence on the fabric quality. The yarns are guided through healds. By moving these healds up or down a so called shed is formed. There are different ways for shedding. The most important ways are the usage of heald frames and jacquard mechanism. Thereby the combination between yarn and heald type has a strong influence on the yarn damage [8][9]. After the formation of the shed, the weft yarn is inserted and beat up against the already formed fabric and the shed positions are changed. For the insertion of a reinforcement yarn like e.g. glass- or carbon-fibre rovings it is common to use a rapier. Weaving looms are usually classified according to their insertion mechanism. [4][5]

There is a wide variety of woven structures that have a strong impact on the composite performance. The way in which the yarns are crossing is described by the weave pattern and influences the appearance and the performance of the fabric. The weave pattern is repeated in both warp and weft direction. The smallest unit that describes the fabric by multiplication is called rapport. The weave pattern is drawn in a simplified scheme, the so called weave diagram (see Figure 2). Each square symbolizes a crossing point of a weft and a warp yarn. The warp yarns run in vertical and the weft yarn in horizontal direction. A filled square symbolizes a warp yarn that lies above the weft yarn at the crossover point. [5]

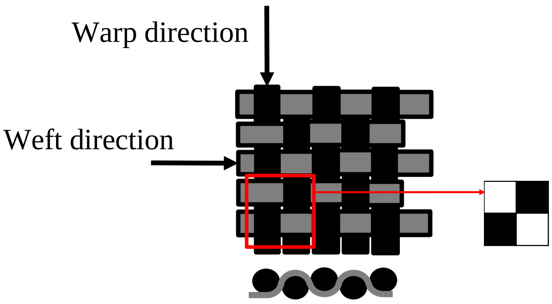

Figure 2: Weave pattern of a plain weave (left) and simplified weave scheme (right)

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Most reinforcement fabrics are either plain, twill or satin weave with different areal weights. Glass and carbon fibres are the most common reinforcement fibres. For series production they are used almost exclusively. [2]

Besides yarn type and weave pattern the most important parameters are:

- Warp- and Weft yarn density [Yarns/cm]
- Production speed [Weft insertion/min]
- Warp yarn tension [cN]

These parameters, except for the production speed, have a strong influence on the crimp of the reinforcement yarns. In particular the weft yarn density has been found to have a direct influence on the crimp. The crimp of the yarns on the other side has an influence on the mechanical performance of the FRP and is subject to current research, not only for woven fabrics. [7]

1.2. A route towards customized fabrics

Up to now it is common to order a standardized fabric from a catalogue of the weaver that fits the demands of the end user the best. A fabrication of a tailored fabric, that means a fabric that is specially designed according to the customer's requirements, is not offered yet. In order to get a tailored fabric that really fits the demands, time and money consuming weave trials have to be conducted. The fabrics have to be manufactured to composite specimens and tested. This approach is - if at all - only reasonable for high mass production.
In order to offer tailored fabrics the public funded project "CustomWeave" aims at replacing these trials with an empirical based model so that based on individual input parameters, the weaving machine parameters can be adjusted alike to produce a tailored woven fabric according to part geometry and mechanical requirements. The conventional and the aspired approach are depicted in Figure 3.

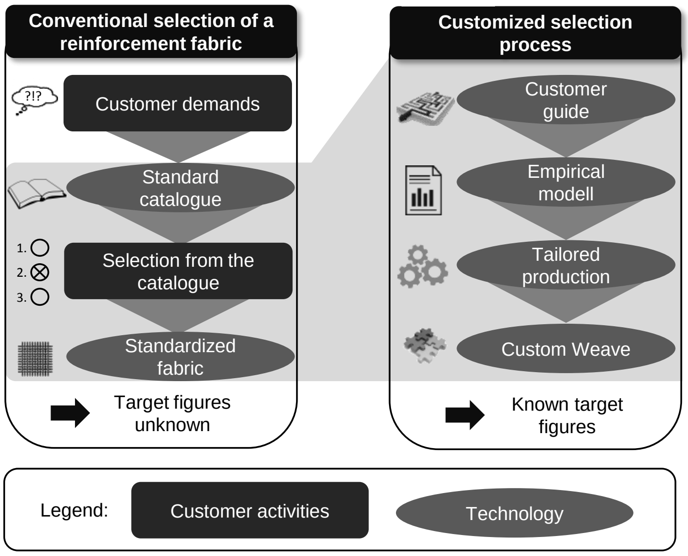

Figure 3: Comparison of a common fabric selection and the aspired customized selection process

In order to achieve this customized selection process, relations between production parameters and the targets figures are established. Therefore extensive testing of both dry and cured fabrics with different production parameters and weave pattern is conducted. The fabrics are produced at Klevers GmbH & Co. KG (see Chapter 2.1). The dry fabrics are tested for their drapability and permeability and

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subsequently processed to GFRP specimens which are tested to measure the mechanical performance (see Chapter 2.2). The collected data are analysed and transferred to an empiric model. Current results of this on-going study are presented in Chapter 3. Two different approaches to achieve the empirical model are described in Chapter 4. Future steps in the project are presented in Chapter 5.

2. Process Parameters and Methods

In this chapter the investigated process parameters and target figures are described and the optimization problem by designing the fabric according to the customers' requirements is shown. Then the design of experiments is shown and the specimen production is described.

2.1. Process parameters and Target Figures

As described in Chapter 1.1 there are different process parameters that have a significant influence on the appearance, costs and performance of the woven fabric.

In this research project the focus is on differing weave pattern, warp yarn tension and weft yarn density. The production speed and the warp density are not investigated. The production speed will always be an individual parameter that depends on the machine and experience of the weaver and will be set to a maximum in order to achieve economic production. The warp density can only be varied by changing the reed and demands therefore a high effort with comparatively low information. The effect of yarn density can be investigated by changing the weft yarn density much more effectively. The equipment and guiding elements for the weaving machine are highly dependent on the knowledge of the weaver and are not investigated within this paper. All other process parameters are varied (see Figure 4).

The target figures for a reinforcement textile can be divided in two groups: The processability like e.g. drapability and permeability and the characteristic values for the mechanical performance of the FRP like e.g. tension strength and bending stiffness. Along with the production costs these groups form a so called "magical triangle". The selection of a fabric for a certain part is therefore an optimization problem.

The target figures investigated in this project are:

- Drapability (dry fabric)
- Permeability (during impregnation)
- Tension strength (cured GFRP)
- Bending stiffness (cured GFRP)

Other target figures like impact behaviour, compression or shear behaviour are not within the scope of this project but might be of interest for further investigation.
The experiments were designed as a factorial set of experiments with the parameters and target figures presented in Chapter 2.1. For each parameter a low and high value were chosen. The weft yarn tension was additionally set to a medium value in order to increase the data basis (see Figure 4). The minimum weft yarn density was chosen so that a just closed fabric was fabricated. The maximum density was set to a value, so that no jamming of the fabric occurs at the beat up.

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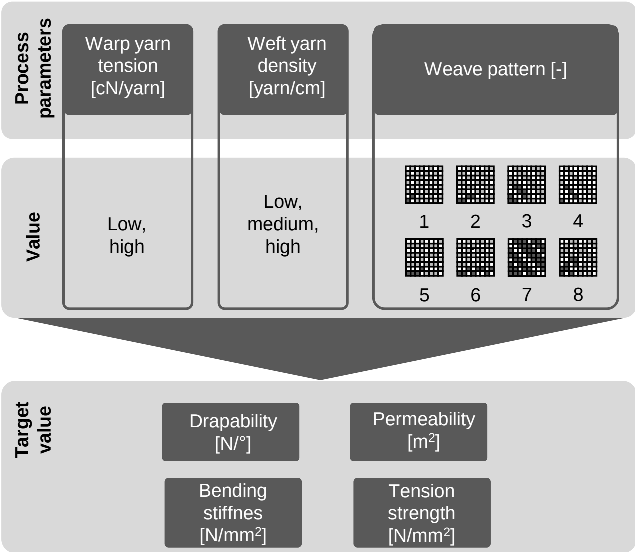

Figure 4: Design of experiment with parameters and target values

2.2. Materials and Specimen Preparation

The glass fibre fabrics were produced by Klevers GmbH & Co.KG on a Dornier P1 rapier loom as it is depicted in Figure 5. Glass fibres with 300 tex were used. Prior to weaving the fibres were wound on a warp beam by sectional warping, also by Klevers GmbH & Co.KG. At least five meters of each fabric version were produced in order to reach a stabilized process.

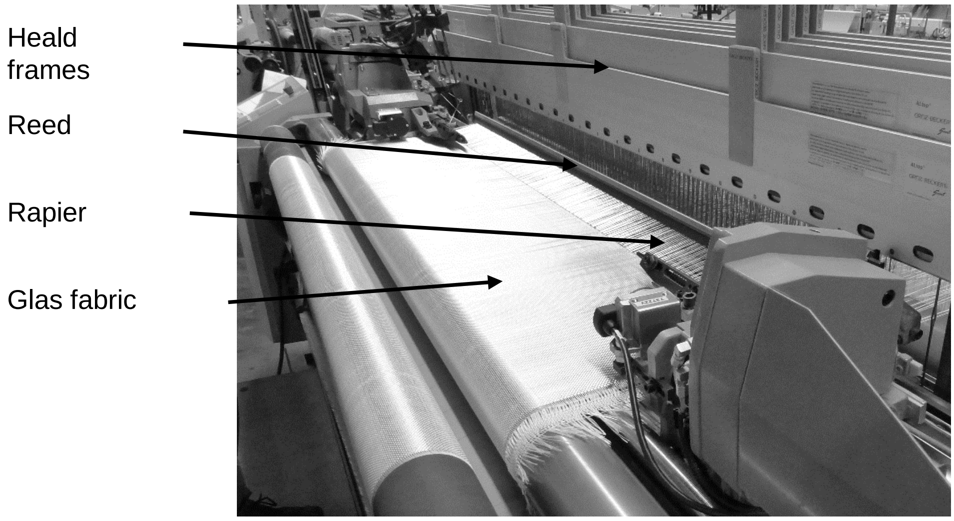

Figure 5: Dornier Rapier Loom with one of the produced fabrics

The fabrics were cut at ITA with a cutting machine Topcut Bullmer Turbocut S 2501 with automated material supply and saw tooth knives. The specimens for measuring the drapability were further cut to rectangular specimens and equipped with tabs made of cardboard. All other fabrics were infused with POLYLITE 420-571 Polyester resin mixed with MEKP FL 505 S hardener and a cobalt accelerator in a flat and rectangular light-RTM mould, so that plates with 2 mm cured thickness are fabricated.

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The specimens were subsequently cut to smaller plates with a water-cooled circular saw equipped with a diamond blade. The sub-plates were equipped with glass fibre tabs and cut to specimens according to the respective standard.

3. First Results

In this chapter exemplary results for the relation between permeability and weft yarn density are presented. The mechanical tests are still on-going and were not available at the time of submission of this paper.

In order to determine the permeability, 6 to 8 layers (depending on the areal weight of the preform) were stacked upon each other and infused using a light-RTM mould as described in Chapter 2.2. The infusion process was filmed and the progression of the flow front was measured over a distance ΔL to calculate the flow velocity v. Together with the known viscosity η of the resin and the measured pressure difference ΔP the permeability K was calculated according to Darcy´s law (see eq. 1). [10][11]

$$K = -\eta \cdot v \cdot \frac{\Delta L}{\Delta P} \tag{1}$$

The results for five specimens with different weft yarn density are shown in Figure 6.

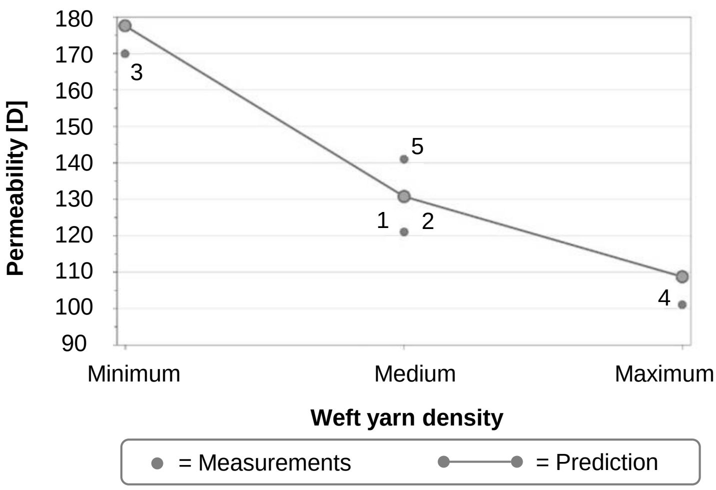

Figure 6: Influence of the weft yarn density on the permeability of the preform

It can be observed that with increasing weft yarn density the permeability decreases. Due to the yet limited number of experiments it is not possible to derive a mathematical relation but with increasing available data from current experiments it seems possible to predict the permeability based on the weft yarn density. This could be an important value for a composite manufacturer, because the fabric could e.g. be tailored to a required time for the infusion or injection process.

4. Database Approach

Aim of the “CustomWeave” project is a customized production of a fabric that is tailored to a certain application. Therefore mathematical relations between the target values and the production parameters have to be established, which requires a broad range of data.

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At the beginning of the project just a few measurements are available. Therefore – as a first step – a customized selection of fabrics is realized using a database approach. Hence a database with the already tested specimens was created. The database includes the process parameters and the associated test results. The requirements of the customer are asked by a software tool, together with the weighting factor of the different target figures. Based on the stored test results, an individual fit is calculated for each weave variation and all of its measured target values. The separate fits are multiplied by the weighting factor of the customer and the best overall fit is chosen. The chosen fabric with its production parameters is then presented to the customer. The method for calculating the overall fit for a weave variation is depicted in Figure 7.

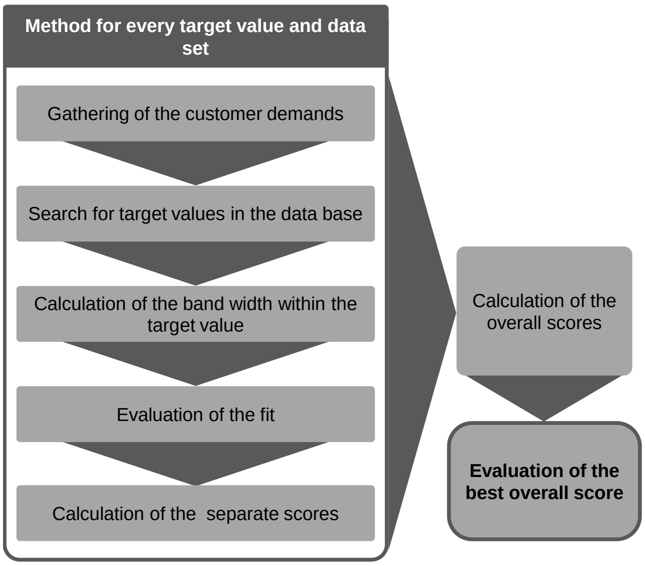

Figure 7: Process steps of the database approach

With this software tool it is possible to have a customized selection of the most suitable fabric and process parameters from the already tested variations with regard to the end user demands.
In a second step the target values of not tested parameter sets shall be predicted. Therefore mathematic relations between the process parameters and target values will be established based on the still on-going material characterization. The process parameters for a given set of target values can be optimized based on the broad database by using evolutionary algorithms, so that a customized fabric can be produced.

5. Conclusion and Future Steps

This paper describes a possible route towards tailored fabrics and the scope of the public funded project "CustomWeave". The most important process parameters for woven fabrics are presented. A broad range of different fabrics are produced and tested. The first results show e.g. significant relations between the weft yarn density and the permeability. A database approach for a customized selection of the best suitable fabric and its process parameters to the customer demands is shown.

In future steps the measured data will be analysed using evolutionary algorithm in order to predict the optimal combination of weave pattern and process parameters. The work will be extended to carbon fibre fabrics.

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