CONTINIOUS PRODUCTION OF BRAIDED PARTS WITH THERMOPLASTIC MATRICES

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Abstract

A hybrid yarn is a thermoplastic yarn combinated with a reinforcing yarn (carbon or glas). The use of hybrid yarn reduces the way for the thermoplastic to infiltrate the reinforcing yarn. This gives more freedom in design and enables fast processes like a pultrusion process. These hybrid yarns can be used in standard textile technologies like the braiding technology. After this step the hybrid textiles are heated, shaped and cooled down in a hot press unit. In an ongoing project called FLECHTTRUSION the braiding technology and the hybrid yarn technology were combined. A pultrusion process for thermoplastic composites was designed and set up. This paper analysis the process requirements and verifies if they can be fulfilled by the FLECHTTRUSION.

1. Introduction

A fiber reinforced plastic (FRP) is usually chosen as a construction material when special characteristics are needed that cannot be fulfilled by metal. FRPs usually have a high strength and stiffness in combination with a low density. This results in excellent specific characteristics and is utilized when lightweight designs are required. Furthermore, FRPs can be designed by modifying the fiber orientation and choosing a suitable fiber-matrix combination [1]. This freedom of design allows the production of parts with no thermal expansion. Today FRP have still the disadvantage that the production costs are high and the process times are long. Thus one main focus of today's research and development projects is to reduce costs and cycle times. A possibility to reduce costs and cycle times is to choose a thermoplastic matrix instead of an epoxy resin.

Thermoplastics have the advantage that they can be melted and consolidated several times. This leads for example to a short production time and to the possibility to recycle the parts. It is still a challenge to infiltrate the textile with the thermoplastic because of its high viscosity. [2], [3] This challenge can be solved by using a hybrid yarn. A hybrid yarn is a thermoplastic yarn combined with a reinforcing yarn (carbon or glas). The use of hybrid yarn reduces the way for the thermoplastic to infiltrate the reinforcing yarn. This gives more freedom in design and enables fast processes like a pultrusion process. A textile made from hybrid yarn can be handled and draped like a standard textile. Thus it is possible to orientate the fiber the way they are needed.[4], [5] In the ongoing project FLECHTTRUSION a hybrid yarn is produced by combining a carbon fiber and a polyphenylensulfid fiber in a commingling process. The hybrid yarn is braided on a mandrel with integrated inserts and after this the braid is melted and consolidated in a rolling station. The aim of the project FLECHTTRUSION is to develop a continuous process chain for FRP. Figure 1 shows the steps of the process.

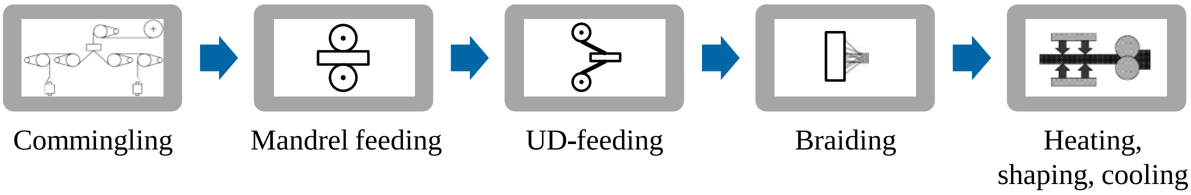

Figure 1. Flechttrusion Process

The paper analysis the technical and economical process requirements and verifies if they can be fulfilled by the FLECHTTRUSION. After this the results of an analysis of the influence of the process parameters on the mechanical characteristics of the FRP is presented. The last chapter is about the future potential of the FLECHTTRUSION.

2. Technical Investigation Process

The process chain is checked by the technical criteria material properties, quality, automation, geometry complexity and possibility to integrate inserts to verify the fulfillment of the target performance. The target performance was detected by literature research and interviews with partners from industry.

Material Properties:
The use of specifically tailored hybrid garn guaranties components with high mechanical properties due to a load-specific design and medium to high fiber volume content. The mixing procedure by the commingling method allows many different material combinations to be used for the component. High performance fibers like carbon, glass and aramid can be used and combined with different thermoplastic yarns like polyamid (PA), polyethylen (PE), polypropylen (PP) or polyphenylensulfid (PPS). The high variety of material combinations and the use of commingling yarn ensures high material properties.

Quality:
The consolidation of the preform to a finished profile is carried out by a hot rolling system. Compared with other pultrusion tool the big advantage of a rolling system is less friction between the tool and the material. This causes less fiber shifts which leads to components with high strength, stiffness and torsion stiffness. In addition, the rolling system puts high pressure at the material during the consolidation period, so that the thermoplastic spreads evenly and the void content is low.

Geometry Complexity:
During production the FLECHTTRUSION allows only small changes in the cross-section geometry. Also, the geometry of the mandrel is limited to simple shapes. The optimal application of this method is for production of very simple closed or hollow profiles. This high specialization classifies the low complexity process. Thus, the requirements are met without overqualification.

Inserts:
For the integration of inserts during the process there is high technical potential. The inserts can be placed on the mandrel and the hybrid yarns can be braided around them. At this stage of research there are still some challenges regarding the consolidation of the braided parts with integrated inserts.

Automation:
The continuous construction of the FLECHTTRUSION allows a high degree of automation. Profiles can be produced with little man power.

It can be shown that the process chain is well suited for the production of profile components in terms of the above tested technical criteria. Figure 2 shows a summary of the evaluated criteria in a network diagram. It can be seen that the process skills can almost fulfill all categories. For an integration of inserts during the continuous process further research has to be done.

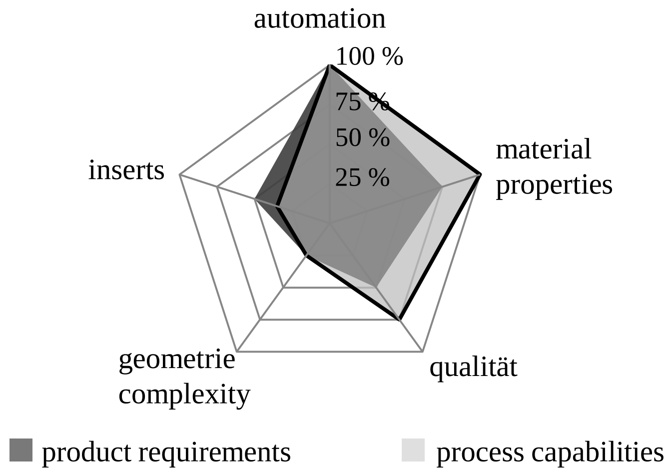

Figure 2. Technical criteria in a network diagram

3. Economic investigation process

There are two main economic indicators: the cycle time of the process and the unit cost. In order to make an economic assessment about the process chain, these indicators were determined for a sample application. In addition, the indicators are represented by changes in process parameters. The cycle time is related to the process speed, which needs to be determined first. In this context the technical feasible speed must be found. The line speed is restricted by the bottleneck of the process chain. It has been observed that braiding and consolidation are the speed-critical units of the FLECHTTRUSION. Machine-hour rate calculation is used to determine the unit cost [6]. For the evaluation of both indicators, a Microsoft Excel tool is provided. It has been developed specifically for the FLECHTTRUSION, but can also be used for other continuous process chains.

Results:
A beam profile similar to a bumper for automotive applications is selected as a reference component. For a component length of 1,1 m, a production capacity of 10.000 units per year and a process speed of 0.1 m/min, the production cost for a variant of carbon-fiber-reinforced plastic (CFRP) are about 46 € per unit,. In this case, the unit price strongly depends on the

cycle time and thus also on the possible line speed. The study also revealed that the proportion of legal costs (investment and labor) decreases exponentially with the increasing number of items (Figure 3).

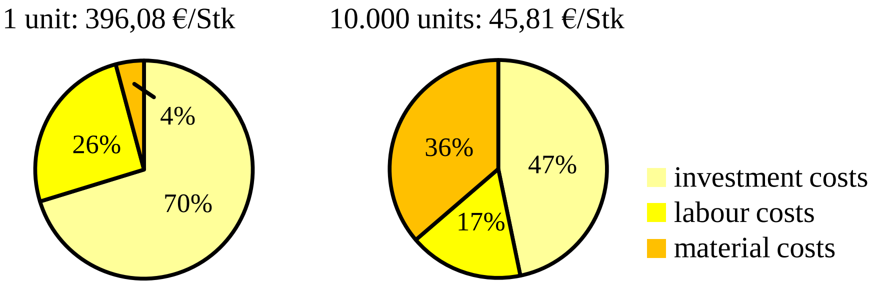

Figure 3. Proportion of legal costs dependent on number of units

4. Mechanical Properties

The final process step is the consolidation process. We use a rolling station with an infrared heater in the middle. The parameters are process speed, temperature and pressure.
To identify the optimum parameter set in terms of bending strength and void content, consolidation trials are performed. The experiments were performed on a testing machine from Zwick Roell GmbH, Ulm to achieve the above mentioned purpose. Figure 4 shows the experimental Setup of the pre experiments.

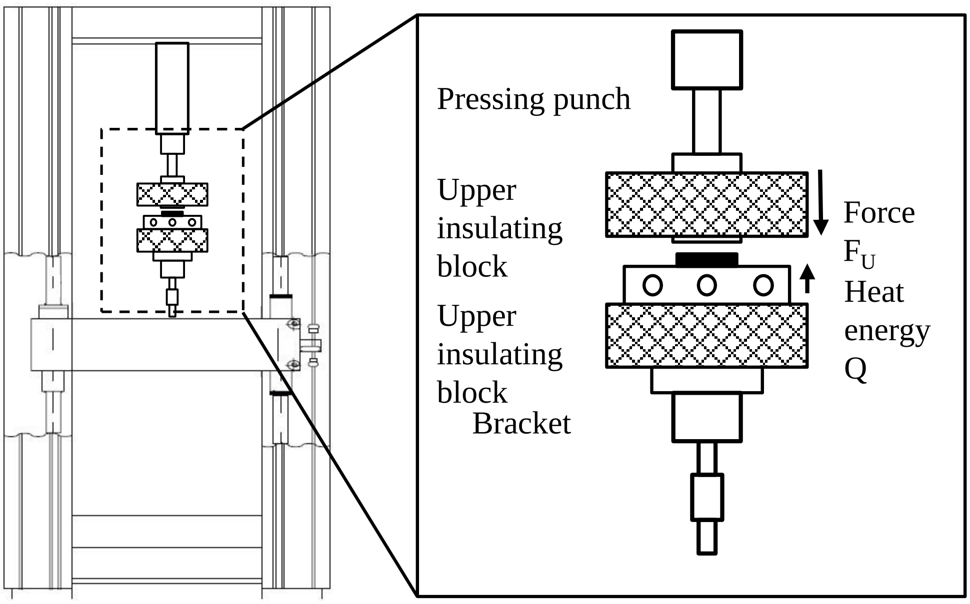

Figure 4 Experimental Setup Shaping of hybrid yarn braids

The sequence of the experiments is described as follows:

- Insert sample, move down the stamp and put up the pressing force;
- Increase temperature from T_{ST} to target temperature T;
- Keep constant target temperature T for hold time t; and
- Reduce temperature to T_{ST} and drive back the stamp.

Parameters \ varieties	Lower parameter	Upper parameter
Temperature T [°C]	305	330

Forming force F_U [N]	500	2000
Holding time t [sec]	40	80
Fabric layers [-]	1	3

Table 1: Experimental parameters

The bending force and the void content of each specimen are measured and plotted out as a function of temperature, force and holding time. The bending strength as a function of temperature is shown in Figure 5.

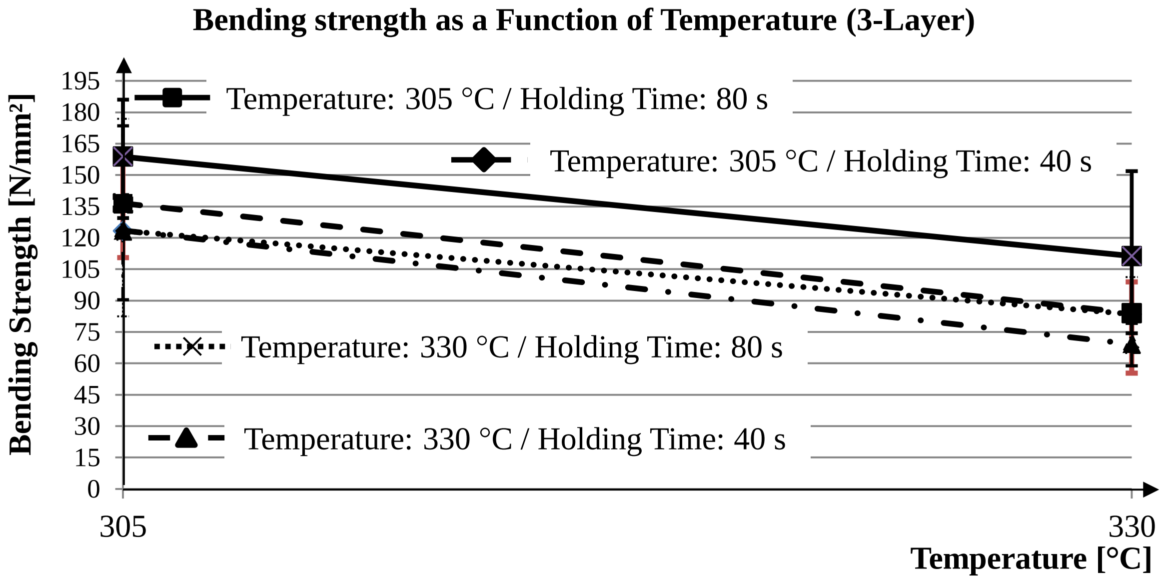

Figure 5 Bending Strength as Function of Temperature

The bending strength decreases with increasing temperature. This is mainly based on the fact that the specimens started to decomposite at a temperature of T = 330 °C, whereby the mechanical properties of a fiber-reinforced plastic may impair massively. The graph of the void content shows a similar tendency. The void content rises with higher temperature.

5. Potential of the Flechttrusion

The criteria used to define the requirements of basic profile components are listed in Table 2. The criteria manufacturing costs, automation and quantity describe the required efficiency. Material properties, quality and complexity related to the technical performances, which the components need to fulfil. The impact of each criterion on the final assessment is listed in Table 2 and is rated subjectively.

Criteria	Evaluation
manufacturing costs	100 %
automation	100 %
quantity	75 %
material properties	75 %
quality	50 %
complexity	25 %

Table 2. Requirements of profile components

The economic requirements of the manufacturing process were ranked very high, while the technical requirements are ranked comparably low. Figure 6 shows a portfolio analysis of the FLECHTTRUSION. The results of the economic and technical investigation are based on Table 2 and the results of an assessment of alternative production methods are based on [7] and [8].

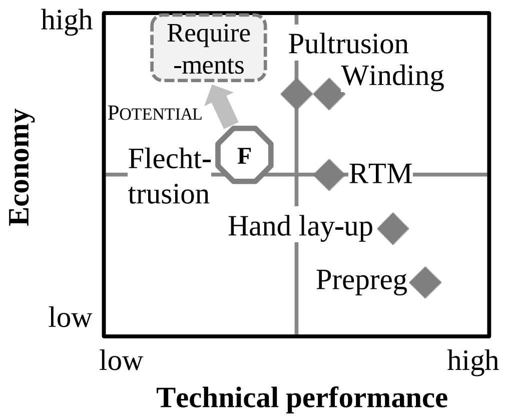

Figure 6. Portfolio of manufacturing processes sorted by qualification to reach the requirements

The use of hybrid yarn promises very high process efficiency that can be achieved by high processing speed with FLECHTTRUSION in the future. The resin transfer moulding (RTM) method, hand lay-up and prepreg methods are unsuitable for the production of profile components and are more uneconomical for profiles. At the moment the standard Pultrusion and winding have a high economical performance depending on the product.

Figure 7 compares the above mentioned processes with network diagrams. It can be seen that Flechttrusion has the best capability for material properties and automation.

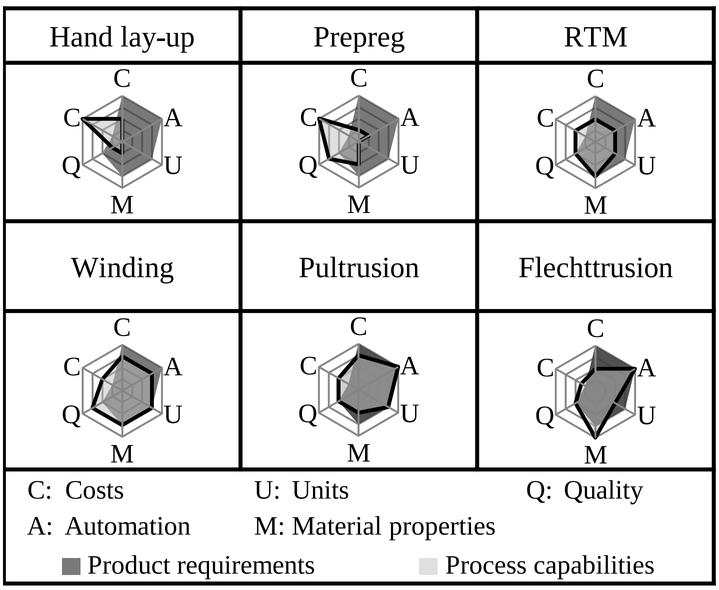

Figure 7. Network diagrams of the manufacturing processes

6. Conclusion

The FLECHTTRUSION is a braiding pultrusion process, which can produce continiously fiber reinforced thermoplastic profiles. In the process a commingled hybrid yarn is braided around a mandrel and consolidated in a rolling station.

In this paper the product requirements for a bumper profile are identified and several possible processes were combined by network diagrams. The production costs for 10.000 units per year were roughly calculated to 46 € per unit.

The bending strength in our experiments decreases when the pressing temperature increases, what might be because the composite started to decomposite at our temperatures. The void content and the pressing temperature are positive correlated.

The development of the FLECHTTRUSION is not finished and there is potential for a high economic process for high performance profiles with the possibility to integrate inserts before the braiding process. So it is not necessary to drill holes into the finished part.

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