COMPARISON OF PROCESS CHAINS FOR THE PRODUCTION OF THERMOPLASTIC UD-TAPES AND ORGANIC SHEETS

A. Erber[1], S. Janetzko[1], S. Spitko[1] and P.V. Brudzinski[1]

[1]SGL TECHNOLOGIES GmbH, Werner-von-Siemens-Strasse 18, 86405 Meitingen, Germany
Email: andreas.erber@sglgroup.com, Web Page: http://www.sglgroup.com

Keywords: UD-Tapes, organic sheets, thermoplastic process chain

Abstract

In the future, lightweight design will become more important for ecological and sustainable mobility due to the shortage of resources especially fossil fuels. Therefore, new design concepts and high performance materials like Carbon Fiber Reinforced Polymers (CFRP) are required. Additionally to the ecological challenges described before, the economic constraints of global mass production markets have also to be taken into account.

Due to their capability for fast manufacturing processes Carbon Fiber reinforced Thermoplastics can be the solution for the described challenges. Beyond that, this class of materials offers sustainable recycling possibilities.

This paper shows the development activities of SGL Group and its partners in the field of thermoplastics along the entire value chain. The main focus is on the comparison of different process chains to produce unidirectional tapes (UD-tapes) and organic sheets. The investigation comprises different technologies and therefore process chains - film impregnation, powder impregnation, solvent impregnation and pultrusion.

Furthermore the paper will present the link between the UD-tape manufacturing process chain and the production of organic sheets. Different process chains and automated layup technologies for the production of sheets based on UD-tapes are discussed.

1. Introduction

New lightweight design concepts and high-performance materials like Carbon Fiber Reinforced Polymers (CFRP) will be used to address the challenges of the automotive industry in the future. For mass production of CFRP's, in particular, there is continuing high demand for cost-efficient materials and process technologies. Composite materials are already used today in many high-performance applications like aerospace, wind energy or based on limited lot sizes also in the automotive industry. These materials offer advantage properties compared to other material solutions like high specific strength and stiffness together with excellent crash and fatigue behavior [1, 2].

1.1. Challenges along the value chain

In the past few years, composites have penetrated the automotive industry on a broader front but still in limited lot sizes. This is due to a number of challenges within the CFRP value chain.

Unlike metals, composite materials are created during the actual production process. Depending on the manufacturing technology used, the reinforcing fibers may be pre-impregnated with the polymer (Prepreg) or placed as a textile in a mold and impregnated with the polymer via infusion, followed by a curing process. It is therefore necessary to harmonize material and semi-finished product properties

Excerpt from ISBN 978-3-00-053387-7

and behavior with the manufacturing process. This is also true for the design of the component. The design has to address the load and application requirements of the structural component but also the characteristics and constraints of the manufacturing process. A ‘design to manufacturing’ approach for CFRP materials is required, when it comes to cost-sensitive high-volume applications like automotive.
Another challenge for today’s composite technology is the material utilization ratio. With a high-performance reinforcing yarn like a carbon fiber, a mechanical performance potential of 4.000 MPa strength and 240 GPa stiffness in the case of, for example, a 50k heavy tow (Sigrafil® CT50-4.0/240-T140) is offered. This potential can be utilized by advanced material technology involving fiber/matrix interaction and load path-oriented fiber architecture within the composite.
High-volume production processes, in particular, require fast material systems in order to reduce processing times and therefore production costs. In this respect, thermoset materials and their related manufacturing technologies are limited by polymer chemistry and the processes required, such as infusion and injection.

1.2. Carbon Fiber reinforced Thermoplastics – technological and market potential

The above challenges confronting today’s composite technology can be addressed by thermoplastic materials which offer different advantages. Thanks to their ability to deliver fast manufacturing processes, Carbon Fiber Reinforced Thermoplastics (CFRT) can be a game changer in terms of production costs for high-volume industries in the future. Besides their potential for cutting costs CFRT’s also offer recycling possibilities that enable sustainable lightweight products. Furthermore thermoplastic composite materials have the potential to interact with other materials in hybrid systems. In addition the thermoplastic material behavior enables well established joining technologies such as welding and introduces the possibility to new repair concepts for composites. In comparison to thermoset materials thermoplastic composites do not have to be cooled during transport and storage which offers again a high cost savings potential.

One key element within CFRT’s is the interface between the carbon fiber and the matrix material. Standard carbon fiber materials with their epoxy based sizing formulations lack in mechanical performance. Hence the full potential of the material cannot be utilized. In that respect SGL Group developed a sizing system especially designed for thermoplastic matrices. With this new carbon fiber for thermoplastic applications a substantial benefit in mechanical performance can be achieved.
Aimed at high-performance continuous fiber-reinforced parts for optimized lightweight designs, most thermoplastic composites are reinforced by low-tow aerospace-grade carbon fibers (3k to 12k) that are relatively costly. By using larger industrial-grade carbon fibers (heavy-tow carbon fibers like 50k SIGRAFIL CT50-4.0/240-T140) both the reinforcing fiber and the manufacturing processes for the thermoplastic component can be optimized in terms of total material costs.

2. Comparison of process technologies to manufacture UD-tapes

Various process technologies – based on different levels or grades of the raw material (especially the polymer) – are known and established nowadays for the industrial production of fully impregnated unidirectional tapes (UD tapes). This section will make a qualitative comparison of four different process technologies based on different raw material systems.

- Film impregnation
- Powder impregnation
- Solvent impregnation
- Pultrusion

Figure 1 shows a schematic diagram of the process flow in the ‘pultrusion’ method. The heavy tow carbon fibers located on a creel unit are spreaded in order to adjust the correct fiber areal weight. The

Excerpt from ISBN 978-3-00-053387-7

resulting unidirectional textile tape is fed into the pultrusion die system where the impregnation of the textile by the thermoplastic matrix is done. The matrix material which is in the initial state a granulate is melted and injected into the die system by an extruder. The screw of the extruder is customized for the polymer grade and polymer type. In the framework of this paper nylon 6 (PA 6) material was investigated and processed respectively. The impregnated unidirectional textile is cooled down and fixated in a subsequent process step. The transport of the material through the entire machine is done by a puller and the tape is spooled in a last process step by a winder on customer specific bobbins.

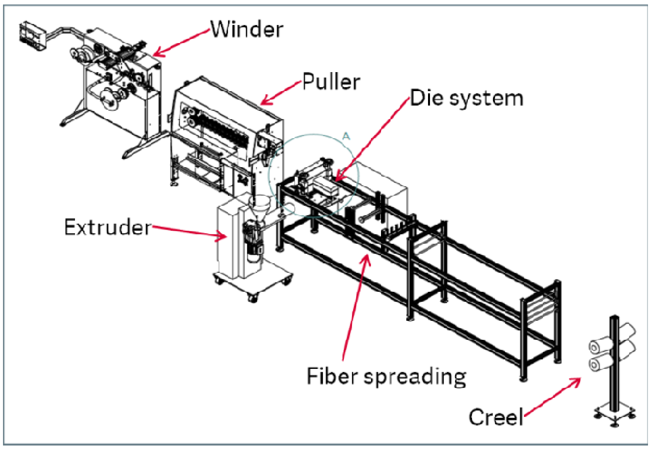

Figure 1. Schematic diagram of a UD-tape pultrusion process.

In the other impregnation methods mentioned above, the process flow of the carbon fiber-based textiles are similar. Here the fibers are also spreaded to low fiber areal weights and the matrix material is applied to the textile. This can be done as powder or film deposition or as a solvent impregnation. Subsequently the material is consolidated in a double belt press process or the solvent is evaporated.
For all four UD-tape manufacturing technologies a slitting process can be used in order to cut a master tape to final width which is required by the used automation system for the production of the components. [3]

In Table 1, the four process methodologies are compared with regard to the flow length of the polymer through the thickness of the textile, process emissions and the homogeneity of the impregnated UD-tape product.

Table 1. Comparison of UD-tape manufacturing processes based on Nylon 6.

	Film Impregnation	Powder Impregnation	Solvent Impregnation	Pultrusion Process
Flow Length	high	medium	low	medium
Homogeneity	medium	medium	high	high
Emissions	low	low	high	low

It can be seen that acceptable homogeneity of the UD-tape can be achieved with all process technologies. The big differences can be seen in the level of emissions and varying flow length. Both parameters have a direct and major impact on process and therefore product costs. Higher emissions mean greater effort and cost for safe and healthy engineering. The flow length through the thickness of the textile is linked directly to impregnation time and therefore to impregnation costs. Nevertheless for

Excerpt from ISBN 978-3-00-053387-7

different polymers an individual comparison of the manufacturing methods which can lead to different results have to be done. Furthermore the selection of the process is impacted by the industry and the individual requirements. If for example a high homogeneity is required solvent impregnation can be for some polymers the method of choice. If costs are the decision driver a powder impregnation with low emissions and acceptable flow length and homogeneity can be the solution.

3. Organic sheets and UD-tape based textile structures

Organic sheets with their individual properties are the backbone of highly integrated parts for serial production of thermoplastic CFRP parts. In respect to the part design the sheets can be customized as shown in figure 2 in stacking sequence, fiber orientation, thickness and textile architecture.
Based on the UD-tapes different stacking sequences can be realized by automated tape laying (ATL) processes as shown in figure 2. Furthermore customized lay-ups with local reinforcements can be produced by ATL processes using UD-tapes in order to realize lightweight optimized structures.
Thermoplastic UD-tapes can also be processed in various textile technologies. One example is the weaving process that can process UD-tapes in widths from 12 mm to 24 mm. These fabrics manufactured on industrial type weaving machines can be consolidated to organic sheets as shown in figure 2. Sheets based on a textile (weaving) architecture offer typical advantages of textile structures such as improved drapeability.

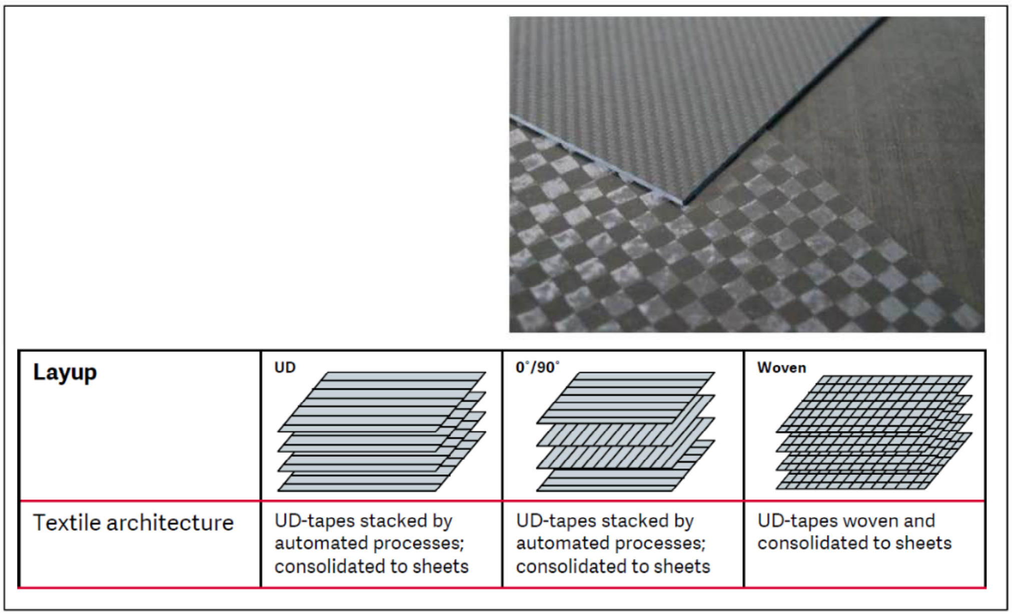

Figure 2. Comparison of different fiber architectures in organic sheets.

3.1. Processing of organic sheets

The pre-manufactured organic sheets, with customized stackings and textile architectures, are heated above the melting point of the polymer by infrared or hot air ovens in a first process step. The heated sheets are transferred into the forming tool which is assembled to a press or is integrated in an injection molding machine. The handling process is usually done by a robot with special gripping units that hands over the organic sheets to the blank holders and fixation needles of the tool. Before the material cools down below its melting point, the tool closes and drapes the sheet into the 3D geometry of the mold. If the tool is integrated into an injection molding machine the injection process of e.g. LFT material is started to overmold the sheets in order to produce complex formed structures. A few seconds later a finished part, whitout the necessity for a trimming process, can be taken from the machine.

Excerpt from ISBN 978-3-00-053387-7

4. Conclusions and Outlook

In summary it can be emphasized that pre-impregnated materials such as CFRT's are an enabler for mass production due to their short processing cycles. The different manufacturing technologies to produce UD-tapes and organic sheets respectively have different characteristics which are mainly driven by the type and grade of polymer material.
On the way to higher production rates the automation systems along the entire value chain still have to be harmonized with the available material solutions. For all manufacturing steps and design concepts based on CFRT's SGL Group offers a comprehensive material portfolio for optimized lightweight components.

Acknowledgments

Some results relating to process technologies for UD-tapes were obtained in a research project carried out within the BMBF puplicly funded 'MAI Carbon' Leading Edge Cluster.

References

[1] G. W. Ehrenstein. *Faserverbund-Kunststoffe: Werkstoffe, Verarbeitung, Eigenschaften*. 2nd edition, Hanser, München, 2006.

[2] H. Schürmann. *Konstruieren mit Faser-Kunststoff-Verbunden*. Springer Verlag, 2007.

[3] A. Erber, S. Spitko. *Expanded role for thermoplastic composites*. Journal of Reinforced Plastics. Volume 58, Issue 4; Jul/Aug. 2014

Excerpt from ISBN 978-3-00-053387-7