Industrialized and digital manufacturing of Thermoplastic Composites

M. Muilwijk[a], R. Yaldiz[b], M. Kremers[a], N. Verghese[c], A. van Zyl[d]
a: Airborne, Den Haag, the Netherlands, b: SABIC, Geleen, the Netherlands, c: SABIC, Houston, USA. d: SABIC, Bergen op Zoom, the Netherlands

Abstract:
Thermoplastic composites hold great promise for automated and faster manufacturing. Individual processing steps like lamination, consolidation, and trimming are typically automated individually. However to truly capture the production line's full potential, an end-to-end automated manufacturing line in which all steps are integrated and automated into a consolidated system, thus producing a constant production flow was developed through a partnership between Airborne and SABIC[1].

Introduction

Thermoplastic composites are increasingly being considered for large volume-scale applications in automotive and consumer products. This increased market penetration both drives and demands a cost reduction of the part in question. Larger volumes drive down material cost, but mass production demands a similar reduction in conversion cost per produced parts. The goal of this line is to demonstrate end-to-end automation with minimized conversion cost in mind.

The Consumer Electronics space offers an interesting opportunity to capitalize on the performance of fiber-reinforced composites because of the general need to go to lighter and thinner structures in the mobile computing and phone space. There is also a volume effect here given that the number of parts tend to be very large, typically in the range of half a million per year. The models also tend to be short lived, which means there is a constant need to stay on top of what the customer's perceived needs are and adapt accordingly with new models. This makes the designed flexibility of the manufacturing line very important. Lastly, beyond structural and aesthetic needs, with the onset of wireless charging as well as the need to embed an increased amount of sensors and antennae owing to the introduction of 5G protocols, there is a major functional drive to obtain radio frequency transparency that limits the use of metals.

All of this creates the perfect opportunity for us to explore the proposed automation driven production approach. The development challenges for this automation driven production approach were identified to be: high speed production, with minimal scrap and minimal operator involvement resulting in low conversion costs, while still maintaining a high degree of flexibility.

Material and End Application

SABIC's carbon fiber reinforced polycarbonate (CFPC) UDMAX™ thermoplastic unidirectional (UD) tape is a suitable material to serve the high volume production requirements of the consumer electronics space[2]. In addition to excellent surface gloss, ductility and low warpage, as facilitated through the use of an amorphous resin and proprietary HPFIT™ impregnation strategy, its properties are also optimized for high volume production besides excellent surface gloss, ductility and low warpage with the amorphous resin.

[1] https://www.compositesworld.com/podcast/episode/episode-17-gino-francato-sabic-arno-van-mourik-airborne-john-oconnor-siemens
[2] https://www.insidecomposites.com/interview-with-gino-francato-global-business-manager-sabic/

The combination of resin and fiber is key in terms of a composite's performance; however, the contribution of the resin itself actually offers many benefits to the ability to make composites in an automated process and providing uniqueness along the value chain. First, the ability to make unidirectional tapes can be considered, where the polymeric matrix can be tuned from a rheology perspective to facilitate improved flow, hence impregnation of fiber tows to provide high fiber volume fraction tapes. In addition, the ability to introduce additives that can impart important properties e.g. flame retardancy, UV stability etc. is very important. From a consolidation perspective (converting individual tape layers/plies to laminates), high throughput cycles are required to meet stringent cost targets, which is again helped by the thermoplastic nature of the polymer resin. Polymer flow (intermolecular) can be tuned, which leads to faster consolidation and better inter-ply bonding. Effects can be tracked back to overall laminate performance (delamination, stiffness etc.) and will help in further downstream operations e.g. overmolding. All of the aforementioned will have a revolutionary effect on the current industry, where processes can be minimized and streamlined, while also offering higher design freedom and cost benefits. During this partnership project between SABIC and Airborne, the tape property was identified as critical for the automation and was improved accordingly.

Design inputs: Conversion cost drivers and flexibility

It is no secret that for automated solutions the two major cost drivers are: 1) amount of scrap generated by the process and 2) labor cost of the process. The aforementioned has significant influence on the design principles of the line.

To achieve the stringent scrap target, laminates are made net-shaped to avoid large cutting losses, and a breakdown was made of where scrap was expected to be produced in the process. One of the aspects, which has significant influence on the scrap, is the quality of the incoming material. Therefore, it was decided not only to inspect the end product, but to also perform a full inspection of the material being fed into the process.

The second major cost driver is the labor costs. Automated solutions generally have the goal to reduce labor cost, hence the production line was designed for minimal operator involvement in mind. The main actions required from a labor perspective are loading of new rolls of material into the machine, and unloading pallets of finished laminate products.
The consumer electronics market is a market in motion with fast changing trends and models. For a composite product, this means that dimension and layup configurations are subject to quick change without inducing significant downtime from a production perspective.

Automation Solution

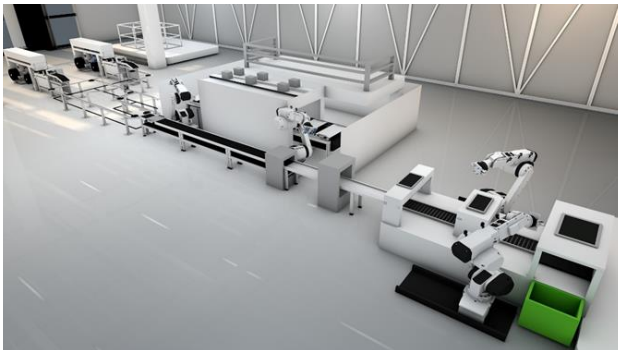

Figure 1 Overview of the line

Considering the aforementioned, the design for an automated production line was approached as a logistics problem. The line was cut into three design parts. The first part is the front end, where the conversion from tape to stacks of plies takes place. The second part is the consolidation step, where the stacks of plies are consolidated to a laminate. The third and last part is the back end, where consolidated laminates go through quality inspection, are trimmed and finally packaged. The capacity of the line is 4 parts per minute, which equals to 5760 parts per 24 hours of production.

Front End Principle

Instead of producing the layup in a single location, product carriers travel on a conveyor track in circles, each time passing feeding stations where one or multiple plies of the layup are inserted. This concept allows for easy expansion by simply adding more feeding stations to the line. When a product carrier has received all the plies, the stack is fixed by ultrasonic spot welding at a designated welding station. The product carrier is designed to ensure accurate alignment of the plies. The product carriers may have a unique RFID tag, so that their position in the system and their contents can be monitored by the line control. From the first ply of a product inserted in a carrier, the product is registered in the line control database with a unique identifier. After fixation, the stacks are taken from the product carrier by a robot and placed into the consolidation station.

Back End Principle

After a 1 minute consolidation cycle, the laminates are placed on a conveyor by a robot. The supporting elements used in the consolidation process are circled back to the front-end of the line for the next cycle. From the conveyor, the laminates are picked up by a robot and automatically inspected for example on dimensions, warpage and surface flaws with a machine vision system. Accepted laminates are moved to the packaging lines whereas rejected laminates are expelled from the line for further analysis.

Inspection and adaptive processing

Early on in the development it was recognized that scrap is an important cost driver. To minimize scrap of consolidated products, it is important to eliminate defects as early as possible in the process.

Therefore, all material that goes into the process is inspected before being cut to plies. When a defect in the tape material is identified, this ply is marked, rejected and ejected from the process. This way, instead of rejecting for example a 10-ply laminate, only a single ply is rejected, which equates to a 90% saving. Figure 2 shows a schematic overview of the material inspection system for tape surface quality, with a camera and light source on both sides of the tape.

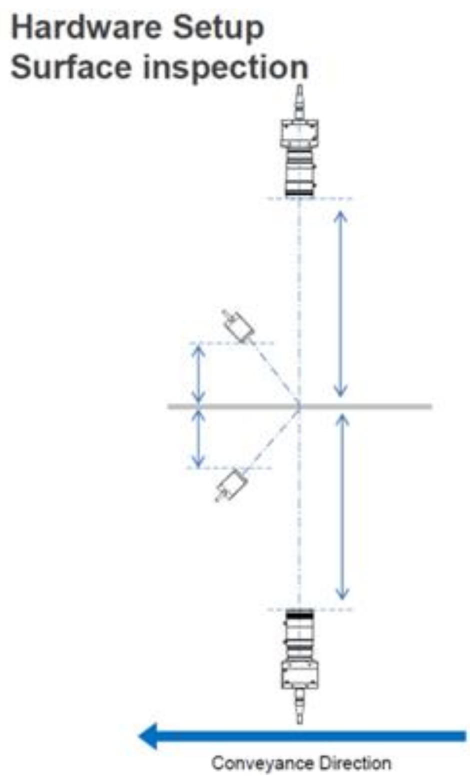

Figure 2 Inspection system layout

Also the spot weld process is monitored digitally and when a weld in a stack of tapes does not meet the designated quality specification, it is automatically separated and not released for consolidation.
After the consolidation step, all laminates are inspected for example on dimensional tolerance and visual appearance. By combining the inspection results of the laminates with the tape inspection process data, all product characteristics can be analyzed to optimize the overall yield. The process can be adapted on-the-fly and machine learning concepts can be used for automated optimization and self-learning. If in the future materials are supplied with 'digital passports', in-line inspection systems might not be necessary anymore as all the information will be digitally connected.

Design for automation

Labor is a significant cost driver so it is essential that the line can run with minimal operator involvement. The line is fully automated, end-to-end: material goes in, product comes out. The tasks foreseen for operators are limited to maintaining the material stock of tape rolls in the front end of the line and refreshing full product collectors at the back of the line. New tape rolls can be loaded while the line is running, the new tape roll is automatically spliced to the previous role. Other material handling and quality control is all done automatically.

Uniqueness
The current automation concept shows uniqueness from different perspectives:

- ➢ It combines high output (1.4M parts/year) with high flexibility. All laminates can have a dedicated layup without impact on cycle time and output.
- ➢ All functionality required for the production of a part is integrated into a single line: laminating, consolidating and inspection.
- ➢ End-to-end automation, there are no manual steps needed
- ➢ Fully digital: all input material and output laminates are automatically inspected and the process settings are adaptable on-the-fly.
- ➢ Flexibility: extra functionality can easily be added by inserting dedicated feeders, for example for other materials, local build-ups, inserts of embedded sensors etc. Also at the back-end more functionality can be added, such as overmolding, 3D printing or welding

Future Improvement Opportunities

The current automation concept is not necessarily limited to conversion of CFPC UD tape into finished thin flat cross-ply laminates. Ideally, the solution could be extended with back- and forward integration to cover tape production next manufacturing steps (i.e. thermoforming and overmolding) respectively.

The back- and forward integration to tape production line and thermoforming/overmolding step may increase efficiency by avoiding logistic complexities as well as multiplication of melting-consolidation steps.

Development Challenges

Typically, new and unique technologies as described here, may require relatively more start up iterations compared to conventional systems in order to optimize the many integrated equipment and process steps.

To obtain a dynamic and robust line, innovative solutions were required to provide significant flexibility of the process steps, e.g. speed of production and the ability to handle a variety of incoming materials and laminate designs.

The design choice to go to net-shape products early in the process results in handling of individual plies of UD tape material. This material can be fragile and buckling of the material must be prevented.

Conclusion

A unique and world-first production process was realized by combining the strengths and expertise from two leading entities, Airborne and SABIC. By utilizing their respective knowledge of automation, integration and thermoplastic composite development a consolidated manufacturing line was created that allows increased production rates and decreased part cost. The production line allows full automation and inspection, which provides the ability to digitize data and facilitate on-line process optimization. In addition, production line flexibility allows material input changes, which makes it possible to capture a broader range of applications without sacrificing unnecessary production down-time. By having the ability to formulate thermoplastics and making unidirectional tapes, SABIC can also tailor materials to help maximize properties, thus producing laminates tailored for specific high volume applications and minimizing scrap.

Appendix – Media Links

https://www.youtube.com/watch?v=FjoLJ2j5qac&list=PLvrbA1nA2I8r8wH-0Bs2Zl07srpOBM0I4&index=11