Increasing the performance of CCM technology

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Abstract:
Continuous compression molding technology (CCM) is an economically and technically efficient process for manufacturing endless fibre reinforced thermoplastic polymers, so called organic sheets. The semi-finished products are fully impregnated and consolidated and can be converted into complex 3D-geometries by a thermoforming process in short cycle times. Actual problems of the CCM-process are the slow production speed and optical defects or shrinkage vacuoles due to pressure losses in the laminate. With the integration of an active adaptive pressing tool and an in-line pressure measurement system the CCM-technology can be optimised towards a homogeneous pressure level inside the laminate. With the developed system, the impregnation and consolidation speed can be accelerated and the production quality improved.

Keywords: Continuous compression molding, organic sheet, impregnation

Introduction

Fully impregnated and consolidated semi-finished products provide an ideal basis for manufacturing efficient lightweight components made out of continuous fibre reinforced polymer composites. By the use of thermoplastic matrices, flat semi-finished products, so called organic sheets, can be heated and converted into complex 3D-geometries within the thermoforming process with short cycle times for large scale production. In combination with established manufacturing processes for thermoplastics, such as injection molding, the potential range of components is further extended.

Production of organic sheets

The continuous compression molding technology (CCM) is an economically and technically efficient process for manufacturing organic sheets. The main advantages of these systems are the flexibility due to the high temperature range and the lower investment costs compared to other continuous systems. Furthermore, there is less material waste at start up and production end. [1]
There are different ways of producing organic sheets with a CCM-System. The most used systems for series production are Film-Stacking set ups and the processing of powder prepregs. [2]

Fig. 1: *CCM-System at Neue Materialien Fürth*

A unique feature of the CCM-machine at Neue Materialien Fürth is the direct melt process (see Fig. 1). The integration of a plasticising unit and a hot runner tool just in front of the pressing unit enables the system to apply thermoplastic melt directly out of the granule onto the dry textile. With this technique variations and modifications of the matrix polymer can be done in line with very less transition waste. On top of that the thermoplastic resin does not have to be foil-shaped or milled in powder form.

CCM-Process

In the CCM-process the raw material layup is guided between two layers of sheet metal to separate the polymer from the hot tool. A forwarding mechanism is thereby pulling the whole stack step by step. Inside the pressing tool the resin gets heated by electrical heating systems and pressure is applied by hydraulic components (see Fig. 2). Thus, the thermoplastic melt impregnates the textile. Afterwards the impregnated filaments are cooled down under pressure by a defined fluid-controlled temperature distribution in the cooling zones of the tool so the layup gets solidified. After reaching the demoulding temperature of the matrix material, the consolidated organic sheet can be separated from the sheet metal. To ensure constant thermal conditions in the press tool, the different heating and cooling plates of the machine are separated from the mounting table by insulation sleeves. On top of that, the plates where these sleeves are mounted is kept on a constant temperature by water cooling. (see Fig. 2)

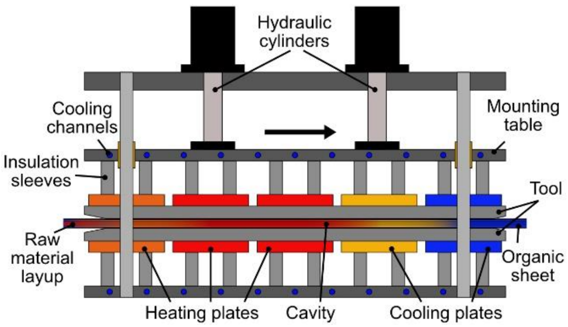

Fig. 2: Schematic press unit of a CCM-System

Challenges of the CCM-Process

Despite the good mechanical properties combined with a low specific weight, organic sheets couldn't achieve full market penetration yet. The reason for this is the high price compared to other light weight material solutions which is mainly caused by the costs for the dry textile and the low output of the fabrication process.

The decisive factor for the production speed is the time required for impregnating the textile with the poor-flowing thermoplastic matrix. To accelerate the production, it is possible to lower the viscosity of the polymer by increasing the temperature in the heating zones, but this is limited by the decomposition temperature of the thermoplastic polymer and the responding interlaminar pressure.

In the CCM-process with flat tools the impregnation mainly takes place in thickness direction. Due to the one-dimensional, transversal flow of the highly viscous matrix around and through the fibre bundles, the time for complete impregnation takes a long period. An optimisation potential would be a two-dimensional impregnation. With a specific adaption of the tool geometry the melt flow front can be controlled and the impregnation can be accelerated by a mixture of axial and transversal flow behaviour through the fibre bundles. [3]

A further challenge in the CCM-process arises from the pressure conditions in the flat tool. The specific volume of the polymer varies due to the heating and cooling process and therefore the pressure differs in a wide range. In relation to the laminate quality the most critical pressure losses occur during the cooling phase, when especially semi crystalline polymers reach their maximum shrinkage behaviour at recrystallisation temperature. At this point the specific volume decreases rapidly and the flat tool is not able to apply pressure onto the laminate, which results in optical defects or vacuoles and therefore in reduced mechanical performance of the organic sheet.

Fig. 3 shows an interlaminar pressure and temperature measurement of a typical CCM-process for the production of a polypropylene glass-fibre reinforced organic sheet. Therefore, a thermocouple and a pressure sensor were integrated in the setup in the middle of the production width. The pressure measurement was performed with a thin high temperature sensor type FlexiForce HT201. The output signal of these sensors shows a strong time and temperature dependent drift and so the real pressure is not proportional to the output signal. Therefore, it is better to compare the output voltage than the calculated pressure. The pressure measurement shows a peak at the beginning due to the solid matrix material. After reaching the crystallisation temperature the sensor voltage stays relatively constant during impregnation in the heating zones. When the temperature of the tool decreases, a rise of pressure is noticeable due to the increase in viscosity. Subsequently, when the thermoplastic polymer reaches its recrystallisation temperature at about 130 °C a pressure drop because of shrinkage is visible.

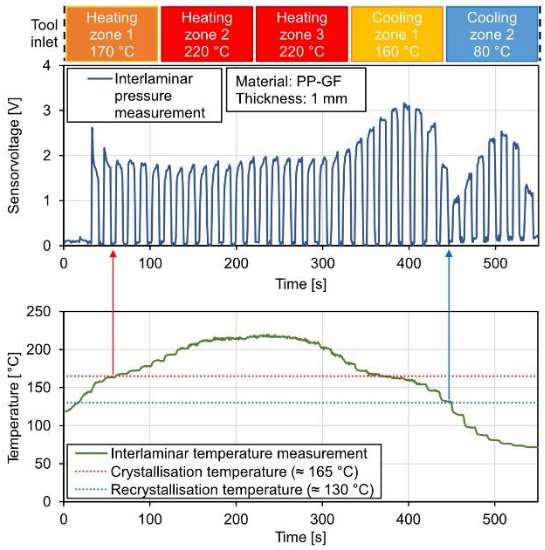

***Fig. 3**: Interlaminar pressure and temperature measurement of a standard CCM-process*

In-line pressure measurement

In standard CCM-machines there is no possibility to measure the actual pressure in the laminate. The use of thin high-temperature pressure sensors like in Fig. 3 to perform interlaminar measurement is very time consuming and the produced organic sheet is rejected afterwards. Furthermore, the thickness of the sensor is influencing the measured pressure.

An in-line pressure measurement system would have many advantages for analysing and optimising the CCM-process. Also, the operator or the system could react on inaccuracies during processing long before the organic sheet is visible after separating it from the sheet metal. So, the quality of the produced material could be ensured.

There are no pressure recording systems available in CCM-machines because it is not possible to measure directly in the laminate due to the sheet metals which separates the laminate from the tool. On top of that the temperatures can reach up to more than 400 °C and most pressure sensors can’t handle these high temperatures.

Neue Materialien Fürth (NMF) developed together with the Institute for Composite Materials (IVW) and Teubert Maschinenbau an in-line force measurement system for the CCM-machine at NMF lab. Therefore, 12 force sensors were mounted between the insulation sleeves and the cooled mounting plate (see **Fig. 4**). The reason for this position is a constant low temperature value and so the independence of high varying process temperatures. Tests showed that despite the distance to the cavity and the steel tool with a thickness of more than 30 mm the sensors can detect differences in the process pressure sensitively. Even though it is not possible to calculate the real process pressure, the location of pressure losses can be detected and so it is possible to react immediately to pressure deviations by optimising the process parameters.

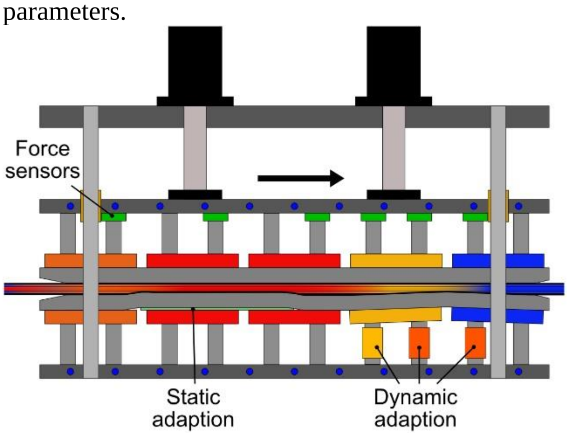

***Fig. 4:** Schematic of the optimised CCM-system*

Fig. 5 shows a comparison of the interlaminar pressure measurement with the developed in-line force measurement. Both curves demonstrate the process in the middle of the tool. It can be seen, that the trends, especially in the cooling area, are quite similar. The differences can be explained by inaccuracies of both systems. The signal of the pressure sensors is very temperature and time dependent and the measured forces depend on the mounting situation. Nevertheless, the results demonstrate, that the developed system is a good method to get more detailed information about the process values in real time.

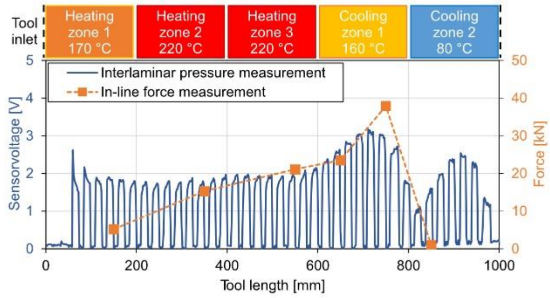

***Fig. 5:** Comparison of interlaminar pressure and in-line force measurement*

Optimisation of the impregnation

To accelerate the impregnation speed, it is necessary to force the thermoplastic melt front in two directions and to adjust the local pressure level at the same time. This two-dimensional impregnation can be achieved by a specific three-dimensional deformation of the pressing tool. To remain as flexible as possible thin aluminium sheets, so-called shims, with a defined contour and thickness were put between the tool and the heating plates (see Fig. 4 left). With the obtained deformation of the steel tool the polymer melt front will be moved from the centre to the outside by every forwarding step of the machine, while simultaneously the pressure drop caused by the macro-impregnation can be compensated. Due to the combined transversal and axial impregnation the pressing time can be reduced and the output increased.

Improvement of the pressure distribution in the cooling zones

The interlaminar pressure measurement as well as the in-line force measurement detect a second drop in pressure at the beginning of cooling zone 2 (Fig. 3). This is caused by the shrinkage behaviour of the semi-crystalline thermoplastic polymer and the thermal elongation of the pressing unit of the CCM-system. The position of the so called “shrinkage gap” is dependent on the used polymer matrix and the temperatures of the pressing tool.

To counteract the effect of the pressure loss, NMF integrated a dynamic adaption system with expansion elements in the cooling zones (see Fig. 4 right). With the in-line force measurement the position and the magnitude of the drop in local pressure can be detected precisely. By a targeted expansion of the dynamic adaption system the pressure can be locally increased and the shrinkage gap can be avoided.

Results

With the developed system tests were performed to proof the functionality of the optimised machine. Fig. 6 shows the pressure distribution measured with the in-line force measurement system. For a comparison the forces of a standard laminate production are compared to the optimised process. The process parameters (temperature distribution, pressing time,

hydraulic pressure, etc.) remain the same for both trials. The only difference is the static and dynamic adaption of the pressing unit.
In the heating zones in the middle of the tool the force of the optimised system is higher due to the integrated shims. Subsequently the force drops under the normal level. The difference between the forces at 850 mm tool length can be explained by the activation of the expansion elements in this zone. The pressure loss due to the shrinkage behaviour of the polymer can be reduced with the new system. Because of material losses on the sides of the tool, the force turns out to be lower than in the middle of the tool.

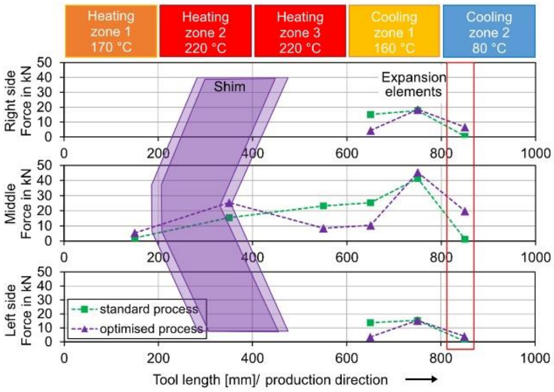

Fig. 6: Improved pressure distribution in the CCM-system

Fig. 7 shows the impregnation progress in the tool during the pressing process. These values were calculated from density measurements. Therefore, test specimen have been produced by stopping the process and freezing the polymer as fast as possible so that the impregnation stops immediately. To analyse the impregnation progress, density tests were performed at different positions of the resulting sample. Due to polymer losses at the edges of the tool, the density can be higher than calculated and therefore the impregnation progress reach values higher than 100 %.
It is clearly visible, that the impregnation progresses faster with the optimised process conditions in the middle of the tool as well as in the edges. These measurements show, that with the optimisation the pressing time can be reduced and so the output rate can be accelerated.

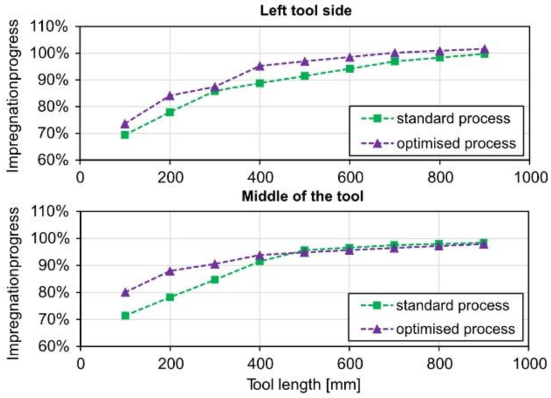

Fig. 7: Impregnation progress in the pressing tool

These results show the first evaluations of the developed machine technology. Due to the high flexibility of the optimised system, further tests have to be performed to exploit the whole potential of the unique CCM-system.

Summary

With the optimisation of an existing CCM-System with a production width of 660 mm it is now possible to improve the impregnation behaviour in the heating zone as well as the shrinkage behaviour in the cooling zones of unknown material combinations. Additionally, the developed static and active adaptive pressing tool and the in-line pressure measurement system enable CCM-technology with product widths more than 1,000 mm and help to increase the quality of the product and efficiency of the CCM-process.

Acknowledgement

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References

[1] M. Neitzel, P. Mitschang, U. Breuer, Handbuch Verbundwerkstoffe, (2014)
[2] A. Wöginger, Prozesstechnologien zur Herstellung kontinuierlicher faserverstärkter thermoplastischer Halbzeuge, (2004)
[3] M. Christmann, Optimierung der Organoblechherstellung durch 2D-Imprägnierung, (2014)