Abstract

Fiber-reinforced plastics are hybrid materials designed for the needs of the 21st century. With their capability to form low weight structures, while preserving high stiffness and excellent damping, these composites provide solutions for a broad range of markets.

Unfortunately, some of these advantages are not used in practice because there exist no fast and automated manufacturing processes for efficient production. In the research field of continuous-reinforced thermoplastic composites, industry is facing a challenge of high viscose polymer melt and thereby an imperfect fiber wet-out. As a result, synergy effects of fibers within a polymer could not be fully exploited.

The topic of this work is to adapt new processing technologies for reactive thermoplastic polymers. On one hand, fast heating and cooling options offer processes with shorter cycle time, and on the other hand, low viscosity of reactive polymers impregnates the textile structures faster. This results in faster and cheaper manufacturing of composites that are yet to be realized for the market.

All FRPCs were produced on a continuous compression molding press. As a non-continuous technology, an inductive heated CageSystem® from RocTool has been selected. Entropically driven ring-opening cyclic oligomers form Cyclics with water-like melt viscosities are chosen as reactive matrix.

The viscosity of Cyclic Butylene Terephthalate (CBT®) was measured using a rheometer. The rheological behavior is determined under isothermal conditions for various temperatures. The chemical transformation from oligomer to macromolecule pCBT[1] was assessed by size exclusion chromatography. Based on these studies, a kinetic polymerization model was constructed which involved an Arrhenius-type equation. By using the activation energy and pre-exponential factor, it was possible to offer an exact mathematical solution for the prediction of isothermal conversion. A numerical solution of the Arrhenius equation helped to predict the polymerization for any time-temperature conditions. Furthermore, the polymerization model was extended to describe the chemo-rheology. Inserting specific material parameters, the bipartite model was able to provide a numerical prognosis for the viscosity with the input parameters time-temperature. All models were calibrated and validated with the experimental data.

[1] pCBT = polymerized CBT® equates the chemical nature of polybutylene terephthalate (PBT)

The continuous compression molding press was used to consolidate CBT-prepregs and PBT-prepregs. As reinforcing phase, a multiaxial non-crimp-fabric from Ahlstrom was used. This fabric contained glass fibers with a "CBT®-compatible" sizing. The design of experiments was mainly focusing on the variation in the temperature distribution in process direction with respect to process speeds. An extensive analysis, from optical to energy absorption, was performed on the resulting FRPC-product, called organic sheet. All test results showed a better performance for GF-pCBT compared to GF-PBT. Even for much higher process speed, the material properties of GF-pCBT did not deteriorate strongly in contrast to GF-PBT. The enhancement was traced to a better fiber-matrix interface (e.g., ILSS values) and to an excellent fiber wet-out with pCBT (e.g., SEM pictures).

Viscosity and impregnation are the main factors behind the transversal visco-elastic impregnation model that was deduced. An arithmetic function that tracks the impregnation process for the classical thermoplastic PBT and its reactive pendant CBT® was derived. This was based on the dimensionless B-factor which was considered as technology independent performance indicator. The model was able to link the fast impregnation with CBT® - the viscosity of which is 10^{-5} magnitude lower than PBT - to all temperature-time-conditions. An optimization method was used to find process parameters to realize a minimum cycle time for the continuous process. This model was adapted to the non-continuous pressing technology to find the minimum cycle time.

To evaluate the economic potential, a transparent process analysis was set up in form of a static cost calculation. In a first step, all monetary activities from each technology were identified and rated. The cycle time - as main capacity indicator - was based on the chemo-rheological model introduced above. Different break-even analyses and production costs highlighted the techno-economic potential of the related process-material-combination. A synergistic effect between innovative process technologies and reactive thermoplastic polymer was found.

Faster and more efficient technologies for the production of fiber-reinforced plastics have been systematically developed and evaluated. The results were achieved with an intelligent combination of manufacturing technology and modern reactive thermoplastic polymers. Moreover, the approach of this work can be transferred to the other reactive thermoplastic matrix-based composites.