Abstract

Endless fibre reinforced thermoplastic sheets (organic sheets) are significantly gaining in importance due to their outstanding characteristics. In comparison to common thermoplastic press moulding composites with random reinforcement like GMT and LFRT they offer remarkably better specific mechanical properties (stiffness, strength). And different from endless fibre reinforced thermosets, they also possess high toughness and show good impact behaviour. Furthermore, they enable welding and have an appreciable recycling potential.

The manufacturing steps, beginning from impregnation and consolidation of the semi-finished sheets up to thermoforming and welding to obtain the final part, represent a closed processing chain. This results in short cycle times and the potential for mass production.

However, this material class is rarely used because of its cost and surface quality problems. Therefore, only a few applications exist as demanding functional or structural parts.

High costs emerge in consequence of either expensive raw materials (carbon fibres, technical thermoplastics) or the sophisticated processing technique concerning the impregnation and consolidation step (double belt press). The surface quality problem is mainly caused by the print-through of reinforcing fibres, which therefore precludes applications in visible regions, especially in the field of automotive exterior panels.

The aim of the thesis was to enhance the chances of application by improving the surface quality of endless fibre reinforced thermoplastics. Thus the surface characteristics and possibilities for reproducible quantitative measuring were identified. Surface roughness, gloss rate, profile amplitude and wavelength as well as short (sw) and long term (lw) waviness were chosen as appropriate values. By varying the type of fibre, matrix, fabric and coating the influence of material parameters on the surface appearance could then be investigated.

It became obvious that the fibre print-through is a result of the significantly higher volume shrinkage of the thermoplastic resin (higher coefficient of linear thermal expansion) in comparison to that of the reinforcement during the cooling process, combined with an uneven distribution of resin and fibres. Thus, amorphous matrices that have no shrinkage due to crystallisation and a preferably small thermal induced density growth lead to significantly better surface qualities (from lw = 60 to lw = 20).

Qualitatively the texture is dominated by the reinforcing architecture. The kind of textile weaving and fineness of the fibre bundles determine the wavelength of the profile deflection.

It was found that the coating has the largest influence on the surface appearance. A common varnish layer with a thickness of only 40 µm enhances the gloss of the substrate which makes the surface waviness even more clearly visible. However, optimising the varnish system with additional base coat or filling layers drastically reduced the waviness but did not raze it completely (lw = 10). Only the application of a thermoplastic varnish layer could diminish the waviness to the desired range below 10 (lw = 4).

Besides the experimental work a theoretical analysis of the consolidation and solidification step was carried out. A finite element model has been created representing a semi-finished sheet with four layers of a 2/2 twill textile reinforcement. Based on this geometry various matrix characteristics as well as alterations of the global reinforcement structure (more or less horizontal ply off-set) have been analysed.

The simulations supported the experimental results. They indicated the strong influence of the matrix and showed that the off-set of the reinforcing layers plays an important role concerning the resulting surface profile. Because the off-set of the plies can not be controlled in the real material and therefore is at random, the profile depths show a remarkable standard deviation (30 %). In the example considering a 2/2-twill reinforcement the optimum off-set could reduce the profile depth up to 40 %.

Furthermore, the influence of the process parameters (pressure and cooling rate) during the consolidation process was experimentally and theoretically investigated. In addition to the non-isotropic characteristics of the textile, the time and temperature dependent mechanical behaviour of the thermoplastic matrix had to be ascertained and transferred into the model.

A rapid cooling rate was identified to reduce the surface profile of the substrate. The profile depth of the simulated GF-PC could be decreased from 5 - 3 µm. However, experimental tests concerning temperature changes and weathering showed that this advantageous effect decreases with time due to the viscoelastic behaviour of the polymer and resetting forces of the reinforcement.

The pressure can influence the texture phenomenon only by affecting the fibre volume content of the sample. In case of static isobaric press processing a certain matrix flow across the margins of the tool can not be totally averted. With a rising pressure the outflow becomes stronger and leads to a growing fibre volume content and stronger surface waviness.

By carrying out several simulations with systematically varying material data a nomogram could be created that represents a tool to predict the surface profile of comparable composites (2/2 twill reinforcement, FVC around 50 %) just in dependence of the matrix. It takes into account the specific matrix volume shrinkage and the pitch from its solidification to usage temperature. Thus, the possibilities but also limitations of a certain material combination concerning surface waviness can easily be estimated.

In order to reduce the heterogeneity of the fibre matrix distribution common textile fabrics were substituted by unidirectional (UD) non-crimped structures and UD fabrics. A newly established processing method was used to manufacture a non-crimped and non-sewed endless fibre reinforced thermoplastic sheet by direct combination of a multiaxial weft insertion machine and a continuous rotocure press. The resulting product proved the potential for an improved surface quality. Despite the use of relatively heavy rovings and not yet optimised fibre placement the surface profile of this new kind of organic sheets is comparable with the one of those samples having the fine 8-H-satin fabric reinforcement (lw = 20).

Finally it could be shown that the method of thermoplastic varnish layer lamination which has successfully been used for semi-finished parts can also be integrated in a thermoforming step to create three-dimensional components. The best results of this trial (lw = 10, sw = 14) do not reach the level of the flat sheets but almost meet the requirements of the automotive “Class A” standard. With regard to economical and weight saving aspects this material option can be considered a competitive alternative to common car body panels.

In conclusion the investigations showed a notable feasibility to improve the surface quality of endless fibre reinforced thermoplastic sheets. Therefore, this thesis represents a contribution to amplify the application potential of this material class, particularly in the fields of leisure and sports goods, and in the range of commercial vehicles.