ABSTRACT

The goal of this thesis was to improve the surface quality of highly reinforced polymer composites in order to make these materials applicable to the painted exterior of passenger cars.

For the evaluation of the application sector of automotive exterior components, a catalogue of requirements was drawn up from technical specifications, internal standards, and legal requirements. Components in the horizontal decorative section of the outer skin, like front hood, boot lid, and roof, have to fulfil the highest optical and structural requirements. A survey of the automobile market concerning applications of fibre reinforced plastics in the exterior of cars showed the state of the art and certain tendencies. So far, only non-reinforced, short-fiber- or random-fiber-reinforced plastics have been able to fulfil the high surface requirements. Up to now, high material prices, the lack of mass production concepts, and insufficient surface quality have prohibited serial applications of CFRP in the outer skin of passenger cars. Therefore, different manufacturing technologies for exterior components in composites were examined and compared in an overview of processes. The process of resin transfer moulding (RTM) was identified to have great potential for serial production because of its achievable surface quality together with high specific mechanical properties of the composites.

The goal of the current research was to find optimized combinations of materials, processes, and coatings, in order to realize a Class-A surface quality for CFRP parts in the RTM process. The main problem with the surface quality is the print-through of the reinforcement caused by the inhomogeneous distribution of the reinforcing fibres and the chemical and thermal shrinkage of the matrix material during processing. In order to perfom a systematic investigation of the composite materials, the process parameters, and surface treatments, an experimental RTM tool with a plate cavity was designed and produced in the surface quality standard of a serial tool.

Within the material optimization the comparison of five epoxy resins showed that the system B2 was the most promising for further investigations with regard to surface quality and cycle time. Within the comparison of the fibre reinforcements, the woven fabrics displayed a minor surface quality compared to the non-woven and non-crimp fabrics. It was found out that multiaxial stitched fabrics with optimized placement technique, texturized, multifilament stitching yarns, and trikot-franse stitching pattern currently provide the best combination of surface quality and processability. Even better surface results were achieved with non-crimp fabrics that are fixed by an adhesive to a polyester mesh. However, the difficult processing and infiltration with matrix material still provide a hurdle to a possible serial application. As a result of the investigation, one type of randomly oriented cut glass mat with minimal fibre diameter and even fibre distribution was preferred as a core material to the commonly used continuous strand mats. Within the great variety of different surface veils, a few types could be identified to offer an effective reduction of long term waviness (from LW>20 to LW<20) and short term waviness (from SW>35 to SW<15). These selected surface veil types are mechanically or binder fixed and made of glass or PAN fibres with an areal weight of 50 to 80 g/m^2.

Statistical methods for the design of experiments and the analysis of the results were used in the process optimization with the epoxy system B2. After the identification of the main predictors and responses a D-optimal experimental plan was designed and perfomed. The method of multiple regression was used to create a process modell which describes the observed system behaviour and deviation to a very high degree.

It was discovered that high pressures on the liquid matrix system right after injection contribute to a high surface quality by compensating a great part of the reaction shrinkage. In order to achieve high pressures in the cavity exceeding 100 bar, the processing and tooling equipment was modified beyond conventional RTM process capabilites. Optimal settings for vacuum and temperature difference depend on tool temperature and post pressure levels. The simultaneous analysis of curing temperature and demoulding time showed that the best surface quality can be achieved if the part is demoulded from the tool as soon as the saturation T_g, depending on the current tool temperature, is reached. Longer curing times neither increase the T_g of the part nor do they improve surface quality. From these results a first strategy for high surface quality can be derived with a high tool temperature and a short demoulding time. The second strategy with a low tool temperature and a long demoulding time, however, is easier and safer to perfom in terms of process stability.

In order to compare highly reactive thermoset matrix materials and to measure the volume shrinkage throughout the whole reaction, a novel shrinkage measurement cell, or dilatometer, was designed. This created the new opportunity to determine the processing shrinkage in its chemically and thermally induced proportions depending on matrix material, curing temperature, and time. Because of the good correlation of the laboratory results with the previous RTM experiments, a high experimental effort for hardware investigations to characterize new epoxy systems can be saved in the future. Matrix system B2 displayed the lowest shrinkage values in combination with a high reactivity. It could also be observed that a great proportion of the reaction shrinkage takes place very quickly after the start of reaction. Therefore, the post pressure on the matrix system must be applied as early as possible in order to compensate this shrinkage. Curing at lower temperatures always leads to lower chemical and thermal shrinkage. In comparison to literature the newly developed method presented in this thesis provides plausible results with high accuracy, and for the first time also for highly reactive thermoset systems.

Surface coatings offer the opportunity to reduce or cover surface structures and defects in order to achieve a high quality of the painted part surface. The exploration of in-process coatings lead to thermoplastic films and gel-coats as technologies with a high potential for the improvement of surface quality. In comparison, epoxy surfacing films and inmould-powder-coatings result in more effort to adapt the materials and application methods to the current RTM process. It was shown that the post-process coating with a plastic paint system contributes to an improvement of the surface quality. In this study different priming coat materials and thicknesses were identified that cover part of the surface texture with an acceptable structure of the coat itself. In addition, two surface finishing methods with manual sanding were found to raise the surface quality of the painted part up to the required standard if required.

The results of the different subsystems materials, RTM-process, and surface coatings can be combined in different combinations of various emphasis to the overall system of the painted RTM-part, complying with the requirements of the specific outer skin region.

Short-term solutions for outer skin parts with vertical surfaces (as A-, B-, C-pillars, sills, or rear side wings) were found and proven with sample plates for the first time. In order to achieve the high quality required for horizontal exterior components (as front hood, roof, and trunk lid) at the current state of development, a higher performance of the subsystems is necessary. But even for this Class-A surface quality, sample parts could be produced for the first time with high effort in the RTM-process. At the beginning of this investigation, sample plates produced in RTM displayed surface waviness values of LW>35 and strong fibre marking over the whole surface. With the combination of optimization results, sample plates with LW<5 could be produced. A visual evaluation could not determine any regular, oriented surface texture.

The presented work showed solutions in material-process-coating-combinations and development potential to reach the required Class-A surface quality of automobile exterior parts with advanced composites. This provides the necessary foundation for further developments with the aim of a serial application.