CONVERGING TECHNOLOGIES - MANUFACTURING OF THERMOPLASTIC COMPOSITES AND INJECTION MOLDING OF STRUCTURAL PARTS

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Abstract

Load bearing polymeric components for automotive applications usually are made by injection molding. This is done to achieve high productivity at low cost. In some case, highly performing, but expensive lightweight components with continuous fiber reinforcement are considered, e.g. HP-RTM parts. However, solutions on half way are rarely found. Although, there are extended and still growing opportunities, especially when employing thermoplastic based composite structures.

Besides of injection molding, which is still the most preferable way for generating the necessary geometric details, there are processing ways with thermoplastic composite sheets (woven-fabric), use of continuous fiber reinforced thermoplastic tapes (non-woven), and direct polymerization of Nylon-6 by means of the T-RTM-Technology. Different processing sequences were studied and compared with respect to productivity and resultant part performance. This led to the derivation that increasingly multi-step processing sequence might be seen that are still enabling cost effective products, when the approach is combined with injection molding and arranged for a fully automated production.

Introduction

For a first instance, manufacturing of composite parts and injection molding are two completely independent things. However, the technologies have characteristics that ask for a combination. With injection molding, fully automated and cost-efficient manufacturing is associated while with the conventional composite technologies, an outstanding technical performance of the resultant products is achieved.

The RTM Processing as well as the SMC processing belong to the most efficient composite technologies since these approaches deliver high-performance composite components whilst the processing itself might be performed in a fully automated fashion. However, in many existent manufacturing sites still much hand labor is seen.

Injection molding normally is performed fully automatic and ongoing improvement of the productive is one of the major concerns. Short cycle time, use of multi cavity molds and reduction of the scrap rate is in the foreground, while some limitation in the molding material’s performance is compensated by an appropriate design. Even a certain necessary weight addition is accepted if the productivity stays high and the requested low part price is achieved.

In contrary, the composites approach with continuous fiber reinforcement is considered at the high-end concerning the resultant lightweight performance. New technological developments bring the concepts from composite manufacturing and those of injection molding closer to each other.

Process Improvements with Thermoplastic Composites

A primary option is increasing the productivity of a thermoset based composite manufacturing where the key factor is automation. Here, the HP-RTM processing is a good example. A fully automated production of the preforms can be combined with handling of the preforms as well as with the resin injection and demolding of the parts from a multi-cavity mold. In a similar way, also compression molding technology is improved in performance, e.g. in the case of SMC processing.

On the other hand, processing technologies for composites exist that directly incorporate as final injection molding sequence, where the processing of organic sheet materials with woven fabrics inside is the most widespread example, Figure 1. As a new technology the processing of unidirectional thermoplastic tapes gets into the focus.

Figure 1: Test geometry for organic sheet components allowing in line-measuring of the thermoplastic composite's temperature during overmolding.

The processing of organic sheet materials was aiming at the performance levels of continuous fiber reinforcement from the very beginning. This is achieved in a typical cycle time of the injection molding machine. Furthermore, extensive functionalization of the composite part is enabled by means of injection molding.

Unidirectional Tapes - "Thermoplastic Prepregs" as a Key for Performance and Success

New technologies deliver new options. The most prominent aspect of unidirectional tapes is tailoring of load optimized blanks that provide a considerably higher lightweight performance, e.g. in comparison to the well-established organic sheet materials. Thus, the tape processing involves a multi-step approach starting with a flat, semi-finished good to a stack followed by a consolidation leading to a tape-blank. The injection molding is the very last step in this process sequence, performed in a conventional fashion that delivers the functionalization of the insert, in this case, of the composite component.

The preceding steps show similarities to the processing of epoxy-based prepreg materials.

This means, the processing of unidirectional-reinforced tapes with thermoplastic matrix can be understood to be a kind of a prepreg processing. Thus, the typical strip by strip laying, which has been developed for the processing of thermoplastic tapes, evolved from the prepreg technology.

However, there is an important difference. The epoxy based prepregs usually have a tacky surface. This means, appropriate roll-application already leads to a solid, still flexible stack that, in an ideal case, is free of remaining porosity. Thermoplastic tapes have a completely dry surface and need to be molten to amalgamate them. In a tape stacking operation, the individual tape cutouts first are spot welded, e.g. with hot pins. This ensures the tapes to stay at the desired location within the stack, Figure 2.

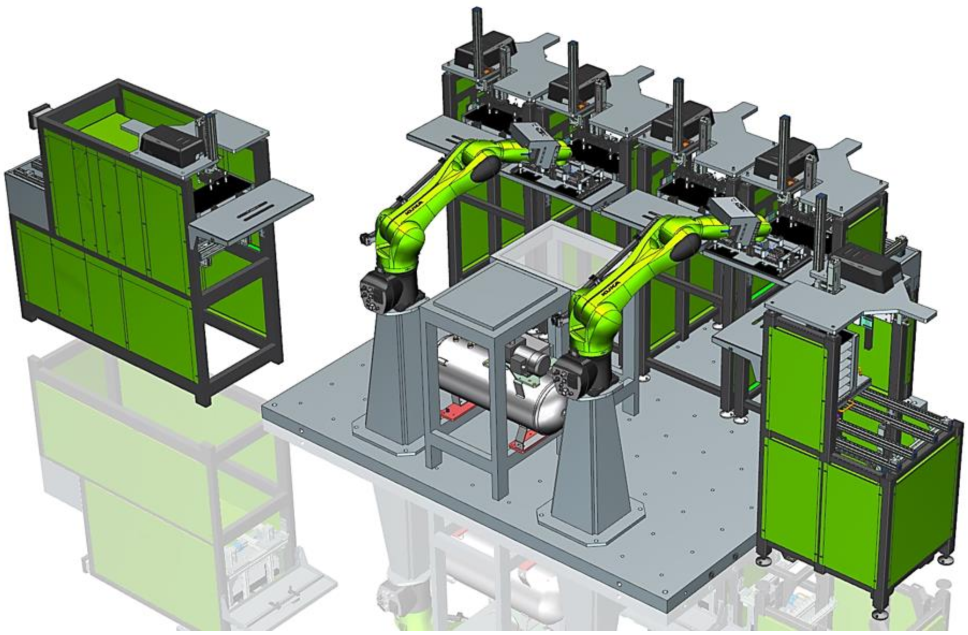

Figure 2: Tape laying cell for the manufacturing of precise and tailor-made tape stacks employing optical measurement technology.

In the next step, a prepreg-stack is either cured in an autoclave or a curing reaction during press forming in a heated mold is conducted. For the autoclave, the stack already needs to the final shape before curing. In the case of the press forming, the stack is brought into the final geometry during closing of the mold. In both cases, subsequent shaping is not possible.

For the tape processing, somewhat different steps are carried out. First, the flat laying stack is consolidated leading to a flat blank. This blank then can be heated in an infrared-oven and shaped to the final geometry using a press mold or an injection molding mold.

The thermoplastic matrix delivers important benefits with respect to cycle time. Whilst curing within the scope of a press forming operation at least requires a curing time of several minutes, the shaping and functionalization of a thermoplastic based tape-blank can be conducted at the pace of the injection molding machine, i.e. with a cycle time in the range of 30 s to 1,0 min.

The processing of thermoplastic tapes employs several important concepts of the processing of thermoset based prepregs. The starting point is a semi-finished product that first is converted into a tape-based blank. The subsequent processing of the consolidated blanks in an injection molding machine is performed in a similar fashion as the functionalization of organic sheet materials.

T-RTM Technology – Injection of Monomers instead of Resin and Hardener

Besides of the technologies that start with a semi-finished product, there is a manufacturing approach for thermoplastic composites where the starting point is caprolactam. In the molten stage, the caprolactam is an extraordinary low viscous liquid that allows good impregnation of dry fibers. Therefore, the T-RTM technology enables the production of three-dimensional composites structures in just one step, beginning with a dry fiber-preform, and where the resultant thermoplastic matrix of the composite is polyamide-6, Figure 3 and 4.

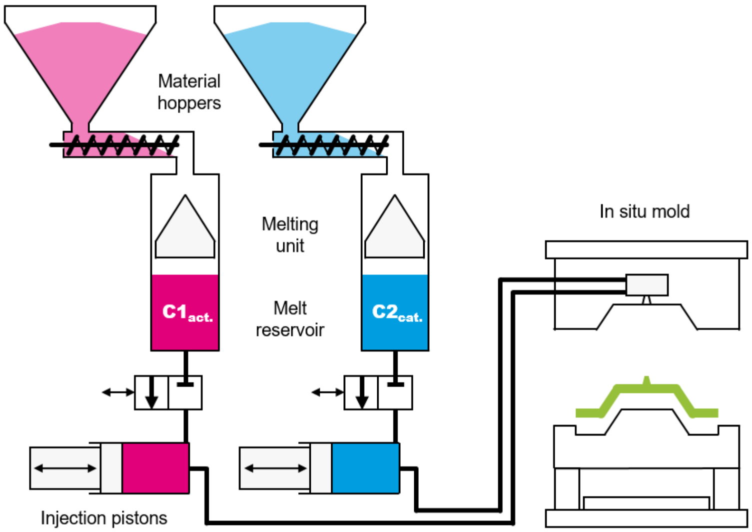

Figure 3: Machine scheme for the processing of epsilon-caprolactam employing dual piston injection.

The thermoplastic matrix delivers a series of benefits. It is possible to achieve good adhesion to the composite parts with polyamide-6 matrix. Consequently, the products might be functionalized by means of injection molding quite easily.

Figure 4: Reactive dosing unit used for the processing of epsilon-caprolactam within the scope of the T-RTM technology. The in-situ polymerization is leading to thermoplastic composite components with polyamide-6 matrix.

Even a welding with compatible thermoplastic materials is possible. Another important benefit is the option of true material recycling. The rejected (new, but showing quality issues) or used (old) composite parts are grinded down to pellets and added to a thermoplastic compound. There, the reused material contributes considerably to the mechanical performance especially with the glass fiber reinforcement.

Furthermore, there is the option of shaping the thermoplastic composites obtained by T-RTM processing afterwards. This leads to a processing conception that starts with a reactive process (as it is the case with classical composites processing, e.g. RTM). Subsequently, for the actual manufacturing of the three-dimensional part, a shaping and functionalization is performed as it is typically the case with organic sheet materials.

Preparation of semi-finished Goods by means of T-RTM Technology

In a composite part, as little as possible of the designated lightweight materials should be utilized. This as an aim not only because of performance reasons, but also because of cost reasons (reduction of overall material usage). Besides of that, as much as possible of the material bought for the part manufacturing should become integrated in the parts that finally will be delivered to the customer (reduction of scrap and cutoff rate).

The making of semi-finished blanks using the T-RTM technology unifies these aspects. First a flat stack of dry fiber materials is produced. This stack can consist of woven fabrics, non-woven unidirectional tapes as well as of mat-based fibrous materials. The layup and the local thicknesses are preset according to the necessities of the resultant part. This dry-fiber stack is consolidated toward a thermoplastic blank by means of the T-RTM-Processing.

The following steps can be carried out in different ways, depending on the predominant requirement of the part. In the case of structural parts, not being associated with high demands concerning the optical quality, it is beneficial to cut or punch the blank already in the flat stage. Then, a one-step operation follows, contain heating in an infrared oven and shaping as well as functionalization in an injection molding mold.

If the resultant surface quality is of high concern, then it is preferable first to shape the T-RTM Blank three-dimensionally after heating in an infrared oven using a simple shaping mold. Subsequently, a trimming of punching operation is carried out on the three-dimensional molding that delivers a neat, load oriented composite shell, which in turn is functionalized using a separate injection molding mold.

Process Modules for integration in a Production Line

It is a typical characteristic for advanced injection molding that otherwise additional processing steps as smartly integrated in the molding process, or special part characteristics are made in just one injection molding mold, which otherwise would require a separate assembly step. Examples are the embedding of metal inserts, the back-molding over textiles as well as the molding of flexible sealing edges using two-shot injection molding.

This conception with a maximum of process integration in a single mold, associated with a shorter overall process sequence, is facing clear limits in the case of production of composite parts. In many cases, the necessary process steps are way to different in nature. The attempt of a process integration would lead to a considerable limitation of the remaining technical options.

For example, one might imagine first to use a steel mold for the manufacturing of a shell-like T-RTM composite part and then, after pulling of cores to obtain the necessary additional cavity space, a subsequent functionalization is performed in the same mold using injection molding.

However, the mold making necessities for a T-RTM process are considerably different from those for the injection molding of a geometrical complex component.

Therefore, it is more useful to utilize conceptions with several process modules where each individual process module is by far less complex. Consequently, this leads to relatively long process sequences, but each individual process step can be set up with reliable and well-known machines and molds. The flexibility with respect to the part design increases considerable since each individual process step can be arranged and optimized separately. Furthermore, if each process module is designed and set up properly, the reduced complexity of each single step contributes to an improved overall availability of the entire production line.

Summary

There are three competing ways for manufacturing of continuous fiber reinforced thermoplastic composite parts:

- Processing of thermoplastic composite sheets with woven fabric
- Processing of unidirectional reinforced thermoplastic composite tapes
- In-situ polymerization of caprolactam leading to a polyamide-6 (T-RTM)

Any one of these processing approaches for thermoplastic composites might be followed by an injection molding process for functionalization of the part.

The classical composite technologies and the injection molding get closer to each other. There are parallels between the processing of thermoplastic tapes and the manufacturing of parts from thermoset based prepreg systems. Furthermore, the T-RTM processing, that leads to final products that are similar to thermoplastic organic sheet components, has important analogies with the classical RTM processing. Finally, the subsequent processing of consolidated tape stacks (blanks) as well as the shaping and functionalization of load optimized blanks obtained from the T-RTM has parallels to the typical processing of thermoplastic composite sheets.

The described processing solutions enable a fully automated manufacturing of continuous fiber reinforced composite parts based on a thermoplastic matrix. However, with these technologies, one cannot avoid the utilization of several processing modules. Nevertheless, when standardized and well tested processing modules are combined, all of the three most important characteristics can be achieved that are full process feasibility, high overall equipment availability, and finally the corresponding high productivity.

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