AUTOMOTIVE VIEW ON LOCAL MATERIAL PROPERTIES – IMPACT ON PART PERFORMANCES AND THEIR PREDICTION VIA SIMULATIONS

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Abstract

In this article an example of a simulation chain for the creation of composite parts produced with the forming process (pre- or thermoforming) and stressed in a crash load case is presented. The different elements of the approach (process simulation and optimization for a defect reduction / elimination and a successive product simulation) are illustrated by the bricks implemented at Faurecia Composite Technologies. Their accuracy is compared to physical trials on a complex automotive example part for both, process and product simulations. The outcome of these validation trials demonstrate clearly the big impact small process decisions can have on the final mechanical part performances.

1. Introduction

The reduction of car fuel consumption by proposing lightweight parts is one of the main strategic goals of Faurecia. Composites as fibre reinforced plastic materials provide an important lightweight potential and Faurecia Composite Technologies (FCT) is specifically dedicated to the development, industrialization and fabrication of structural and non-structural composite parts.

One of the main issues preventing the mass-market introduction of composites in the automotive industry are the relatively high raw and semi-finished material costs. Thus only with an overall optimized part design combined with new processes and material offers one can aspire to replace existing metal structures in a common car. In the automotive context, the part design relies generally on mechanical FEA simulations which validate that a part does not fail when fulfilling its functions.

Compared to standard engineering materials, fibre reinforced composites are more complex due to possible anisotropies in the material. This anisotropy is induced, or depending on the fiber structure, at least reinforced during processing [1]. Not considering the manufacturing and the induced local material properties in the mechanical simulations could lead to not robust and costly part designs [2-4]. Thus process simulations should be used to validate and optimize manufacturing in the design process.

Continuous fiber reinforced composites have generally better material properties than those based on chopped fibres (e.g. GMT, SMC). For structural applications, their use can thereby provide a further weight gain compared to other materials. Main industrial process families, identified for the fabrication of continuous fibre reinforced composite parts at automotive cycle times are the resin transfer moulding process (RTM) and the thermoforming process [5]. Such fast cycle times (about 1 part every 1-2 minutes) are primordial when developing and producing cost effective composite parts.

In both processes, the RTM and the thermoforming process, a main process step consists in the shaping of the initially flat fibre material into the complex 3D geometry of the final part, as shown in figure 1. These forming operations can be complex and may induce many defects into the final part. While certain defects are acceptable in non-critical zones or when having only a negligible impact on the mechanical performances, parts presenting other defect configurations must be discarded as waste. Thus it is necessary to predict and master the presence of defects by optimizing the process, for example by adapting the stamping sequence or by modifying the clamping. Performing a stamping optimization after the mold fabrication would demand important investments. Thus numerical process optimization should be engaged before finalizing the part design.

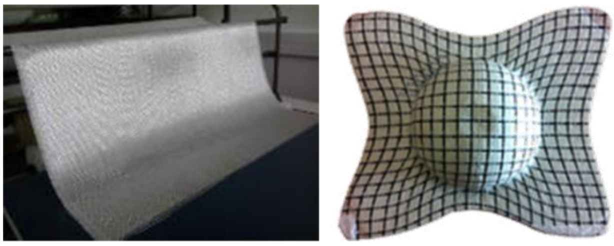
a) Material on roll b) Formed material

Figure 1. Continuous fibre reinforced composite material forming

Additionally to the prediction of defects in the part, process simulations allow to reduce the number of costly and time-consuming physical trials, to increase the process profitability for example by a cycle time reduction and to extract information about the final material configuration which has, as already stated, a major impact on the mechanical part performances.

As the latter are used for the final part validation in product simulations, correct local material values are primordial for designing optimal composite parts. A tool for the data transfer between process and product simulations is necessary and is a basic element of the simulation chain.

In this work, the entire environment for a successful coupling between product and process simulation is demonstrated with a part, produced by forming and stressed finally in a crash load case. In chapter 2, generalities about the simulation chain and composite part simulations including material characterization are put forward before speaking in chapter 3 about forming simulations and in chapter 4 about the product simulation and the simulation coupling. A summary of is given in the conclusion.

2. Composites simulations

2.1 Simulation chains

As stated in the previous chapter, a part design approach relying on simulations is mandatory in order to create cost efficiently composite parts. It will basically be a link of process and product simulations via a mapping and if necessary a homogenization of local material properties. From an automotive point of view such a simulation chain should contain:

- Reduced computation efforts for process & product simulations enabling part optimizations
- Identified main material properties having an impact on mechanical performances

- Simulation tools able to predict and handle these properties
- Reduced number of software codes in order to reduce software license cost
- High prediction accuracy, including the solely use of in real live measurable input parameters

2.2 Simulation strategy

A large number of software codes exist on the market which can be used for the simulation of one or multiple aspects of composite materials. A selection of the adapted software codes can be determined by the availability of (material) models for the selected processes and product simulations, the accuracy and the licensing costs. Additionally it should be verified that the communication between the different software codes is possible, which is guaranteed if the same code is used for both simulations.

For FCT, the main software code for mechanical simulation has been chosen with LS-Dyna. In order to guarantee the smooth transfer of process data, doing process simulations with LS-Dyna is thus favoured. Even if this is not possible for all processes, the forming process can be modelled with LS-Dyna as such a simulation is generally done with an explicit FEM solver. Furthermore steady developments as e.g. the creation of the material law 249 enhance the predictability of the code [6].

For the mechanical simulation a multitude of composite material behaviour and failure models are already implemented in the code. The selection of the adapted material model is thereby largely steered by the desired output accuracy and the necessary effort for the material characterization.

2.3 Material characterization

Due to the local anisotropies of continuous fibre reinforced composite materials, an important characterization effort is necessary to put into place correct material models for the differnet simulations. Most characterization should thereby rely on samples in order to reduce expensive trials on sub-systems or entire structures, according to the trials pyramid, presented in figure 2.

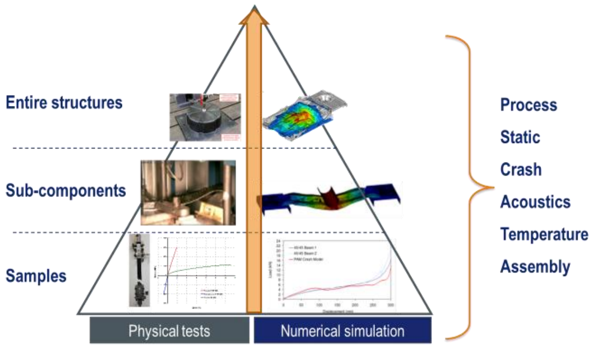

Figure 2. Classical composite material characterization pyramid

Depending on the executed simulations, different material parameters must be determined. For a forming simulation important values include the in-plane fibre shear, the bending behavior or the friction coefficients between distinctive composite plies and between the composites and the metal mould.

Once all necessary material parameters determined, the successive process and product simulations can be done.

3. Forming simulation

Multiple forming examples can be found in literature. Most often a hemispheric dome, as shown in figure 1 is used for the demonstration and validation of forming simulations, see for example [7, 8]. Real automotive parts present much higher complexities. Thus a more complex part, see figure 3, will be investigated in this work.

Figure 3. Example part for trials and simulations

3.1 Project description

The here presented project is coupled with an evaluation of dry fabrics preforming on the preforming centre developed by the Fraunhofer ICT together with Dieffenbacher [9]. The main particularity of this preforming centre is the possibility to do sequential stamping. The idea is to form the material step by step in order to reduce the occurrence of fibre wrinkles. Additionally different clamping configurations can be used to increase locally the fibre tensions and reduce thereby additionally the wrinkle formation.

By these two means it is possible to modify largely the forming kinematics of the part. These are fundamentally linked to the induced local stress state which is at the origin of local defects. Thus it is possible to enhance the final forming result and to reduce occurring defects as wrinkle development by optimizing the forming kinematics. In order to avoid a time consuming trial and error determination of the optimal forming kinematics, process simulations were realized.

3.2 Simulation predictions and correlation

Different materials have been used for the forming trials and simulations in order to investigate about the impact of the basic materials and the weaving structure on the formability. As the prediction of a defect intensive example is the most interesting and challenging, the here presented work will concentrate on a non-crimped fabric (NCF) carbon fibre material. 4 plies of this material are formed in each trial with a stacking sequence of [0/90°; ±45°]s.

As already mentioned, LS-Dyna with its material law 249 is used for the simulation of the forming process at FCT. Once the material data determined, further important steps are the contact and boundary conditions definition. For the latter the exact localization and the displacement definition can be challenging and should be reported exactly for comparison trials.

Figure 4 compares the results of simulation and real preforming trials. In this figure the good wrinkle position predictions of the simulation model are illustrated for the tested configurations.

Figure 4. Correlation Trials-Simulation

The prediction quality is constantly high for all different tested materials. It is also independent of the applied forming sequence which is the basic condition for a successful forming kinematics optimization.

3.3 Forming kinematics optimization

The trial facility has 3 stamps which can be closed independently of each other. The goal of the optimization was to find the stamping sequence which reduces the wrinkle number in the part as much as possible. Due to a reduced number of feasible configurations, a manual optimization has been selected in this example. An automation using an optimization software is possible and recommended for configurations with more possible optimization parameters. This is for example the case when developing a new product for which the geometry of the stamps can be chosen freely.

Figure 5 illustrates the results of the optimization approach: By the optimization of forming kinematics of the NCF material it was possible to largely reduce the wrinkle number in the exterior and interior plies. Especially the latter is much more complex when working with real trials as the destruction of the preform is necessary when trying to validate the presence or absence of wrinkles in the final part. Furthermore it is much more costly and complex to modify already produced stamps when it is asserted, that no convening configuration is found.

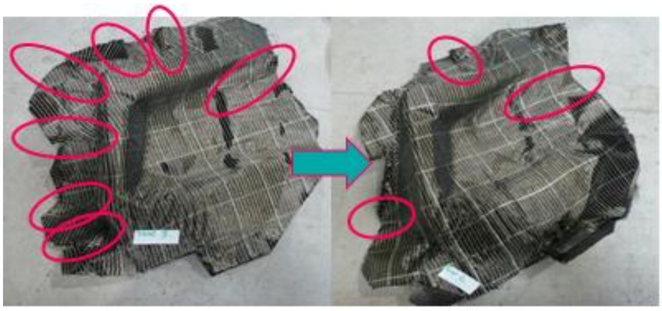

Figure 5. Wrinkle reduction

For the other in the project tested materials a configuration without any wrinkles can be found for this geometry. The optimized part configurations having no or only small zones with wrinkles it is possible to create physical parts which can be tested in crash situations.

4. Product simulation

4.1 Material parameter mapping

Dynamore developed recently a tool, Envyo [10] which can be used for the mapping of local fibre orientations, extracted of a process simulation, onto the mesh of a product simulation. The utilization of such tools is very important if the crash behaviour of the part shall be predicted in a realistic way.

4.2 Crash trials and simulation

In the automotive industry the final part performances are always the main indicator for a part validation. Thus a crash load case has been set up for the part and checked with crash trials and simulations, see figure 6. The correlation between simulation results and the second crash part configuration can be seen when comparing the figures.

Figure 6. Crash simulation result with highlighted failure zone

A comparison of the crash behaviour of parts, produced with different stamping sequences has also been done in this project as shown in figure 6. The only difference between the two shown parts was the stamping sequence during production. As the failure zones differ largely, it can be stated that a small modification of a process parameter as the forming sequence can have an important impact on the mechanical part performance. This concerns the failure zone and also the energy absorption which is different for both configurations.

This failure influence is best visible for the NCF carbon fibre part as the wrinkles, eventually created during part production increase the defect influence. However, the same failure zones are recorded for the other material configurations which break eventually at different energies but with the same correlation between stamping sequence and damaged zone.

5. Conclusion

The crash trial results, presented at the end of this work demonstrate the important influence of the manufacturing process on the final part behaviour. This underlines the necessity to consider the manufacturing process when conceiving a composite part regarding its mechanical part properties.

An optimization of the process parameters is theoretically possible after producing first stamps and moulds. However an approach using simulations and optimizations will be much more efficient due to a reduced need of time, cost and effort. Additionally the freedom in the stamp geometry selection is higher and it is much easier to modify the part shape (in accordance to specifications) in order to simplify the part production. The accuracy of current models has been illustrated in the different chapters of this article.

All in all, the elements of the simulation chain for formed (and with the RTM process infused) composite parts as implemented at FCT has been laid out in this article. Future work to enhance this approach can be an automation of the different steps and an efficiency increase of the characterization methods. Additionally, a methodology should be developed, which allows the consideration of the wrinkle impact on the mechanical properties of the final part. With such a methodology it is eventually possible to accept a certain amount of defects in some local zones if the global part behaviour is guaranteed or even to create predetermined breaking points.

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