LOWFLIP - DRAPING SIMULATION OF PREPREGS AT MESOSCOPIC AND MACROSCOPIC LEVEL

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Abstract

To establish carbon fibre reinforced plastics, the improvement of the virtual process analysis is a key factor. Therefore the draping simulation of prepregs and semipregs is one point amongst others in the project LOWFLIP which is funded by the European Union.

This paper deals with different meso- and macroscopic models suited to preimpregnated biaxial and unidirectional (UD) non-crimp fabrics (NCF). Different material characterisation tests are described and their results are presented. Based on these results, the material parameters of the simulation models are adjusted.

To evaluate the simulation models, draping simulations and experiments are performed using the double dome geometry [1].The comparison shows a good correlation of the established macroscopic models in shape and also a good correlation of the mesocopic models in the local draping effects. In contrast to the macroscopic approach, mesoscopic approaches allow to predict effects like fibre slippage, gapping and in-plane ondulation, which is a valuable gain of information.

1. Introduction

For industrial areas with high production volumes it is important to predict and optimize the manufacturing process. This circumstance is especially important for the production of carbon fibre-reinforced plastics, when they are compared to established materials such as light metals. Therefore the simulation of the draping process is one part in the EU funded project LOWFLIP, which deals with the cost-effective production of carbon fibre-reinforced parts by using out-of-autoclave prepregs.

The finite element simulation of the draping process with macroscopic approaches is widely spread and numerous commercial software are available. This method allows prediction of various draping effects. However, to get a detailed idea of the fibre paths, the macroscopic models are not sufficient. Therefore the mesoscopic draping simulations are subject of research [2]. On the one hand simulations at the mesoscopic scale can predict the position and shape of every single yarn, but on the other hand a much higher knowledge of the material and higher calculation capacities are necessary.

The following work shows mesoscopic and macroscopic approaches suited for different types of prepregs and semipregs. Besides the material models, the material characterisation and the validation of the models are outlined.

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2. Material characterisation

In this paper it is dealt with a sewed biaxial NCF semipreg, a biaxial NCF semipreg with scrim bonding and a unidirectional prepreg without bonding yarns (see figure 1). The difference in their architecture leads to different forming behaviours and mechanisms. Due to that circumstance, each material has to be characterised by suited approaches. Therefore cantilever, bias-extension and friction tests are performed. In the following chapter the experiments and their results are presented in parts as well as their qualification to characterise each material.

a) sewed biaxial NCF semipreg b) UD prepreg c) biaxial NCF semipreg with scrim bonding

Figure 1. Close-up view of the different materials, used in this paper

2.1. Bias-extension tests

To characterise the shear behaviour of the materials with biaxial architecture, the bias-extension test according to [3] is performed at room temperature and 80 °C. To provide the defined temperature in the fabric without influencing the textile, an infrared heating with a contactless temperature sensor is installed.

Figure 5 shows the results of the different bias-extension tests. The influence of the resin’s viscosity can be observed at the example of the sewed ncf semipreg, which is tested at room temperature and 80 °C. The decreased viscosity at this elevated temperature leads to significantly lower forces during the bias-extension test as well as to a raised locking angle. The different types of sewing are influencing the shearing behaviour especially at high shearing angles, whereas the influence at low shearing angles can be neglected.

2.2. Friction tests

Due to the absence of bonding yarns the UD prepreg has a weak bond between the fibres. This circumstance leads to low deformation forces in transversal direction and for shearing. This behaviour is mainly dominated by the resin properties. The low deformation forces in comparison to the other materials in this paper lead to a dominating influence of the process’s boundary conditions on the deformation. Therefore the friction conditions are investigated as described below.

The draping tests and simulations in this paper are performed with single layers, therefore only the tool-prepreg interface is investigated as shown in figure 1. In this test rig, a stripe of the prepreg material is stacked between two heated plates, which consist of the same material as the draping tool does. The prepreg is pulled out at a constant velocity while the extraction force is measured. This force correlates twice the friction force F_R of one contact area.

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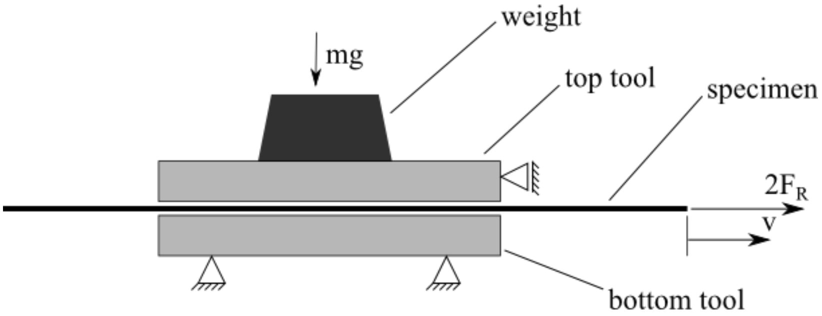

Figure 2. Schematic draft of the friction test

Figure 3 shows the performed experimental parameters as well as their results. A dependence on the friction stresses of the relative velocity and the contact pressure can be observed. The relations of friction stress and contact pressure decrease by increasing contact pressure, indicating the velocity dependence as well as a strong influence of the resin.

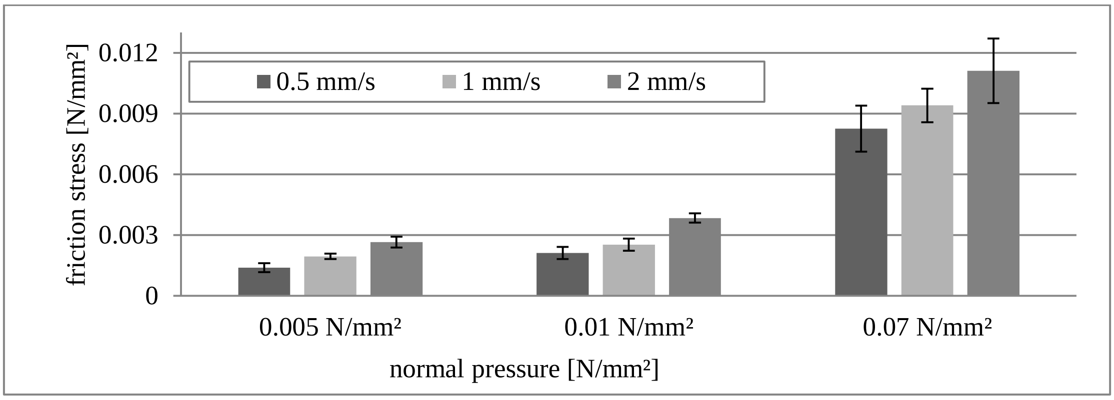

Figure 3. Results of the friction tests at 80 °C [4]

3. Material modelling

As mentioned in chapter 2, the paper is dealing with three different textiles, consisting of the same type of fibres and resin but differ in their architecture. Therefore different deformation effects [2] dominate. In the following chapter one model for each material is presented. The models are based on different approaches which correspond to the materials properties.

3.1. Mesoscopic model of a biaxial NCF semipreg

The sewed NCF semipreg consists of three different materials; biaxially arranged carbon yarns, sewing yarns and resin. A feature of the semipreg is that only half of the NCF is impregnated and therefore the resin mainly influences only the deformation of one of the two carbon fibre layers.

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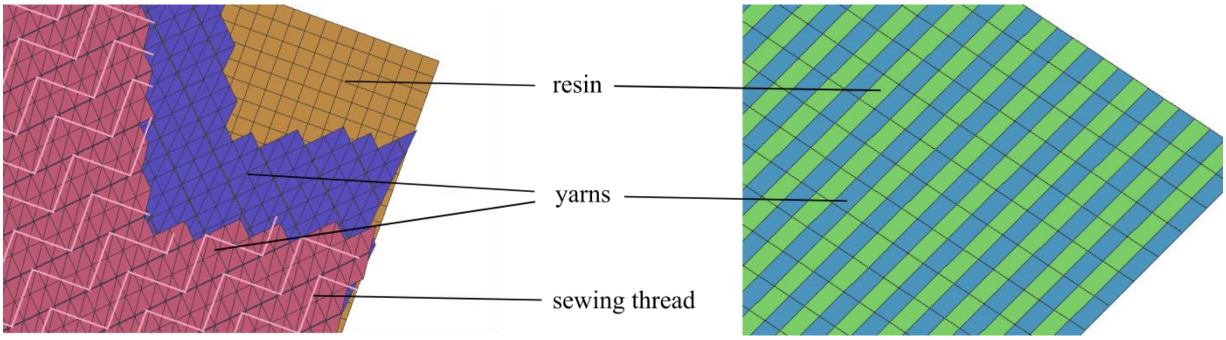

a) mesoscopic model of sewed NCF b) mesoscopic model of UD prepreg

Figure 4. Mesoscopic simulation models of a sewed NCF semipreg and of an UD prepreg

As shown in figure 4 a) the yarns are modelled by shells with an orthotropic, linear elastic material model [5] whereas the sewing threads are built of bar elements using a simple linear elastic material model. To describe the resin, an additional layer of shell elements with a non-linear, plastic deformable material model is implemented. This layer is connected to only one of the carbon fibre layers by tied elements to simulate the special characteristics of the semipreg.

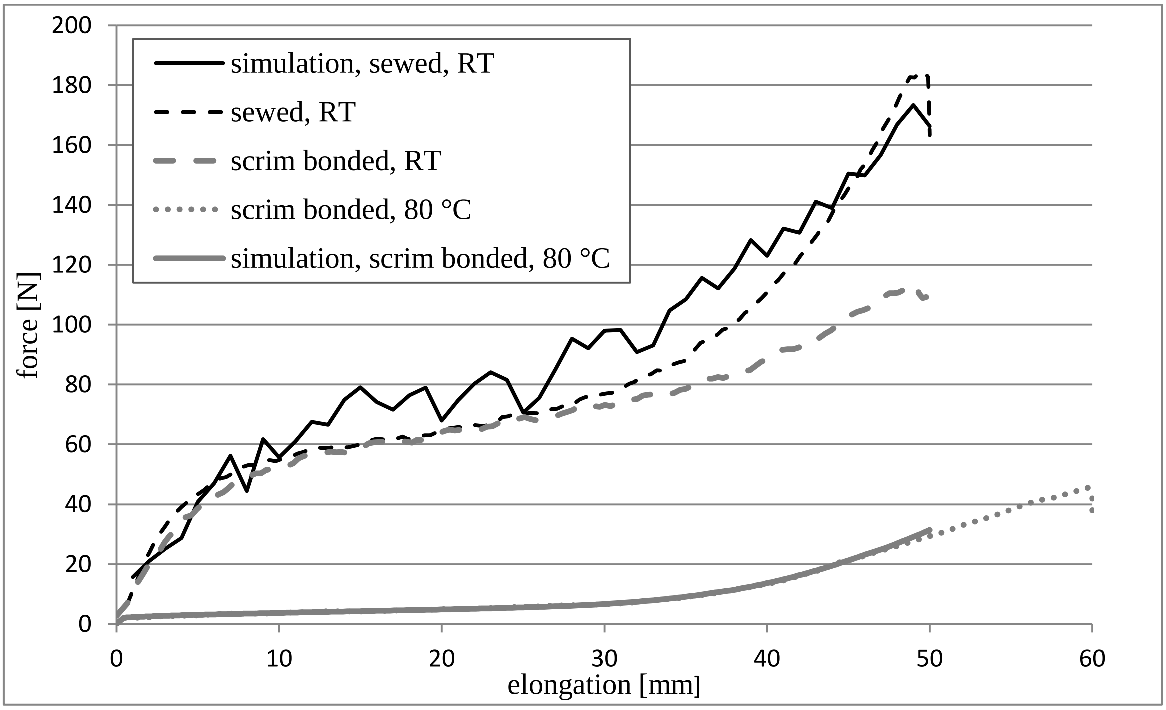

Figure 5. Comparison of bias-extension test experiment and simulation with fitted material models

Due to the material's complexity of the NCF semipreg and the interactions of the three different components, the material parameters are determined by fitting the simulation of the bias-extension test to the experiment (see chapter 2.1). A good qualitative and quantitative match is achieved. It can also be seen that the experiment shows a smoother trend than the simulation does.

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3.2. Mesoscopic model of an UD prepreg

In contrast to the other materials in this work, the UD prepreg material consists only of resin and carbon yarns. Therefore the dominating deformation mechanisms differ to those of the other used materials. By the production of the prepreg material the boundaries of the tows disappear and a material with nearly equally distributed resin and carbon fibres is achieved.

Figure 4 b) shows the mesh of the material model. It consists of shell elements which describe two different materials equally aligned in stripes. The carbon fibres are described by an orthotropic, linear elastic material model which is the standard model for macroscopic draping simulations of biaxial or unidirectional textiles [5].

The resin is described by a visco-elastic material model which is based on Maxwell's material model [5]. This allows to simulate the low bonding forces in the prepreg, which are dominated by the viscous resin behaviour. Gapping during the forming process can be emulated by elimination of resin shell elements. This option is triggered by a defined thinning of the elements. The advantage of thinning in comparison to stress or equivalent stress is, that shearing of the elements has a minor influence on the element elimination.

The contact modelling is based on the friction test results described in chapter 2.2. Therefore the friction stresses τ_R are computed dependant of contact pressure p and relative velocity v by the following equation (Eq. 1) [5]:

$$\tau_R = f(p)g(v) \cdot p. \tag{1}$$

It is presumed that the friction is not dependant to the sliding direction, because only tool friction appears in the examined draping simulations and the model is designed for a fully impregnated UD prepreg, which means that the fibres and the tool should be mainly separated by resin.

3.3. Macroscopic model of a biaxial NCF semipreg

The macroscopic model of the biaxial NCF semipreg with scrim bonding is using a non-linear elasto-plastic macroscopic material model [5]. It takes the behaviour of a whole composite ply into account without any focus on particular constituents' properties. There are several essential material parameters describing the macroscopic material model, like the density, the shear stiffness and the Young's modulus in the fibre directions as well as the orthotropic bending stiffnesses. The shearing behaviour of a composite ply at forming temperature is the most important characteristic for draping simulations with macroscopic models therefore the parameters are fitted to the bias-extension test as shown in figure 5.

4. Draping simulation and validation

The draping tests for the validation of the draping simulation as well as the draping simulations with the different material models are described in the following chapter on the basis of a generic geometry.

4.1. Draping tests

For the validation of the draping simulations, draping tests are performed at the draping test rig of the Institute of Aircraft Design (see figure 6). This test rig allows moving one or more punches controlled by force or velocity and apply forces by pneumatic cylinders which are used as blank holder forces.

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In this configuration a heatable mould and a heatable stamp with the double dome geometry are used. The blank holder, which is made of sheet metal, covers the area around the geometry. The blank holder forces are applied by four pneumatic cylinders in the corners. Each cylinder applies a force of 290 N and the stamp is moving with a constant velocity of 0.5 m/s².

The draping tests are performed at constant temperatures of 80 °C or room temperature, then the closed tools are heated up to the consolidation temperature. The draped and consolidated parts are measured afterwards by a three-dimensional measurement system to compare it to the simulation results.

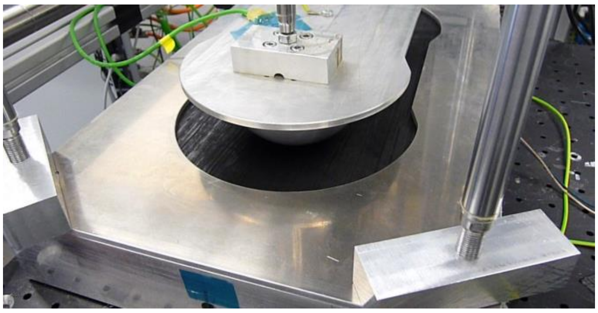

Figure 6. Draping of the UD prepreg

4.2. Sewed biaxial NCF semipreg

Figure 7 shows the scanned surface of the draped part and the simulation result. For a better visualisation the sewing thread is not shown in the draping result. The same tendencies in the outer shape can be observed. However, the draped part shows a higher cross directional drawing-in. Furthermore, the simulated geometry has more wrinkles in the blank holder area. But still the simulation shows gapping in the double curved, convex areas, which correlates with the experiment.

The differences may be caused by the discretisation of the yarns and the sewing threads. The discretisation and parameters of the yarns does only allow low transversal compression and no transversal bending. A finer discretisation and lower compression strength in longitudinal direction could improve the results, but would also lead to stability problems and increased calculation times.

4.3. UD prepreg

In figure 7 a good correlation of the gapping positions can be observed. The simulation shows less but larger gaps. This effect can be explained by element elimination, which simulates the gapping. At the moment, the elements are eliminated, a weak point is generated, which propagates through the model.

Next to the possibility of the gapping prediction, the main advantage is the low computation time of the model. Due to the macroscopic character of the mesh, a calculation time comparable to macroscopic models is achieved.

The differences to the experiment can be explained by the different physical effects. Whereas the resin in the prepreg is mainly located in the capillaries between the fibres, it is described in the simulation by a macroscopic material formulation. Therefore microscopic effects are influencing the draping behaviour, which are not taken into account in the mesoscopic model.

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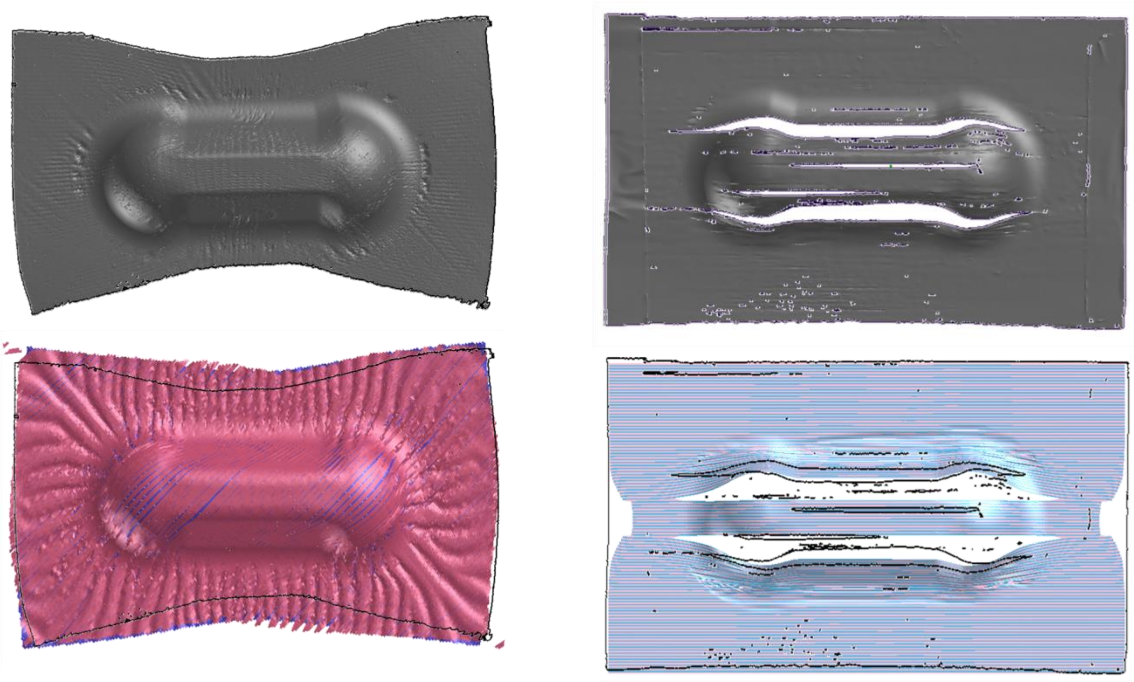

Figure 7. Comparison of the draping results (upper) and the simulation results (lower) of the sewed biaxial semipreg (left) and the UD prepreg (right)

4.4. Biaxial NCF semipreg with scrim-bonding

In a macroscopic model no sliding of particular UD layers of NCF reinforcement can be taken into account, a whole ply is modelled as one layer of elements. A comparison of the scanned formed part and the draping simulation result is shown in figure 8. It can be seen, that the outlines are corresponding very well. The maximum in-plane deviation is about 4 mm.

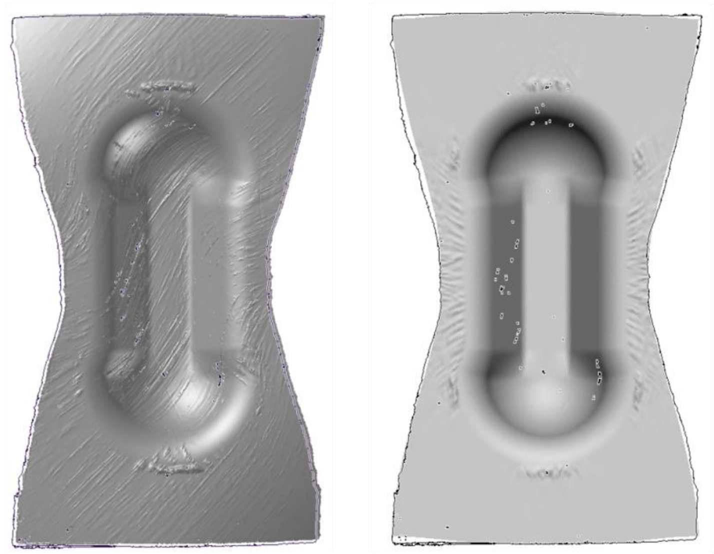

Figure 8. Comparison of the draping results (left) and the simulation results (right) of the scrim bonded biaxial semipreg

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A good coorespondance of the visible defects’ size and position is observed between the simulation and the experiment. Especially the bulges at the lower and upper end of the geometry are predicted very accuratly.

A good correlation of the final draping simulation result and the real formed part is observed. Differences in the fibre orientations are mainly caused by the macroscopic model itself, where sliding of UD layers cannot be modelled.

5. Discussion and Conclusion

The results show, that the main draping effects can be simulated with all three material models. However, every model has its special advantages and disadvantages. The macroscopic model, which is state of the art, is a good method to predict drawing-in and wrinkles. To get a detailed view of the draping process, it is appropriate to use mesoscopic approaches. One of the main benefits is, that those models are able to simulate fibre slippage, gapping and in-plane undulation. However, to show the draping effects in their real dimensions, the examined mesoscopic models have still to be improved. Also the adjustment of the material parameters is very time consuming, due to the amount of parameters and the calculation time of the simulations.

In following researches, the models have to be tested in multi-layer architectures on real draping parts. To improve the mesoscopic models, further investigations in yarn based characterisation tests as well as new numerical material formulations for yarns are necessary.

Acknowledgments

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