EVALUATION OF THE JOINING MECHANISMS OF POLYMER METAL COMPONENTS

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Abstract

Based on experimental results of pull-out test with hybrid specimens a modeling approach is presented. The pull-out specimens consisted of long fiber reinforced polyamide with 40 weight percent glass fibers (PA6.6 GF40) in combination with a car body steel. The experimental results of four tested configurations showed that the force transmission is based on the three joining mechanisms: force fit, direct adhesion and form fit. For the finite element simulation each of the joining mechanisms was at first modeled separately. A simulation considerung all mechanisms showed a good agreement with the experimental data.

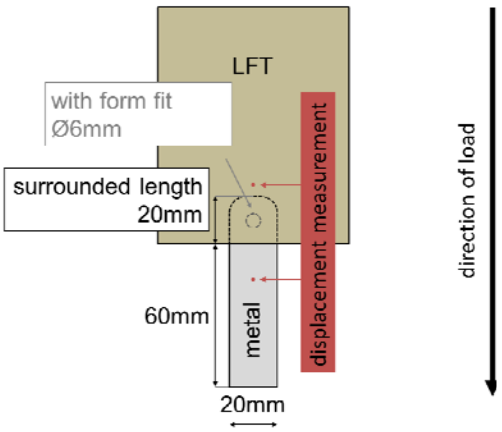
1 Introduction

The demand on the reduction of CO_2 emission and with that the reduction of fuel consumption leads to a constantly increasing need of lightweight components in the automotive sector. One possibility for the reduction of weight is multi material design. The goal is to apply each material such that it's beneficial properties can be taken advantage of. Examples are polymer metal structures where polymer and metal are combined in one part.
Polymer hybrid structures have been utilized in cars for several years. The Front End of the Ford Focus is an example [1]. The potential of polymer hybrid structures has been pointed out by Gruijic et al. [2].
A further development of classic polymer hybrid structures with short fiber reinforced polymer is the usage of long fiber reinforced thermoplastics (LFT) manufactured in a press process [3]. The advantages are the improved material properties of the LFT. In long fiber reinforced polymer metal hybrid structures the metal is only used in highly loaded areas of a component. One of the research interests is the joining of the polymer and the metal. There are two principle possibilities to join the two materials: *post molding assembly (PMA)* or *in molding assembly (IMA)*. Examples for PMA are parts with adhesive joints or rivets. With IMA no additional assembling step is needed, but the joining possibilities are limited. One possibility is joining with form fits. The metal part is stamped [4] or punched and the polymer melt can flow through or in the hole. Another possibility is joining based on direct adhesion [5]. In this case the adhesive properties of the polymer are used so that the polymer part acts as the adhesive and a joining partner at the same time.

In order to evaluate the deformation and damage behavior of polymer metal hybrid parts appropriate finite element modeling approaches are useful. In this paper results from finite element simulations of different joint configurations based on form fits and direct adhesion which were derived from experimental results are discussed.

2 Experimental Results

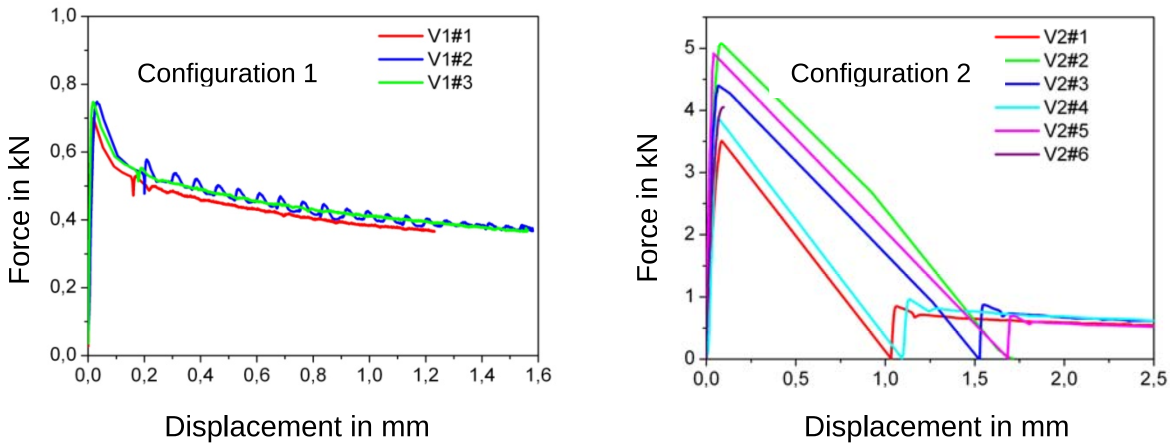
The finite element simulations are based on experimental investigations of the hybrid joints. In [6] results of pull-out tests with four different joint configurations each with two material combinations are presented. The tested materials were on the one hand long fiber reinforced polyamide 6.6 with 40 weight percent glass fibers (PA6.6 GF40) and on the other hand long fiber reinforced polypropylene with 30 weight percent glass fibers (PP GF30) each in combination with the steel HC420LA. The configurations varied in the pre-treatment of the metal; while two configurations were tested without pre-treatment the other two have been exposed to abrasive blasting using corundum. Moreover, the beneficial influence of a form fit on the mechanical properties realized by a hole in the metal inlay was investigated. The test specimen and the tested configurations are shown in Figure 1.



Configuration	Form Fit	Pre-treatment
1	-	-
2	-	blasted with corundum
3	Ø 6mm	-
4	Ø 6mm	blasted with corundum

Figure 1. Geometry of the pull-out test specimen with test configurations

The finite element modeling is based on the test results of PA6.6 GF40 and the steel HC420LA which are illustrated in Figure 2. The four tested configurations exhibit each a completely different force-displacement behavior. Thus, the conclusion is drawn that the three different joining mechanisms force fit, direct adhesion and form fit are acting in different combination and strength.



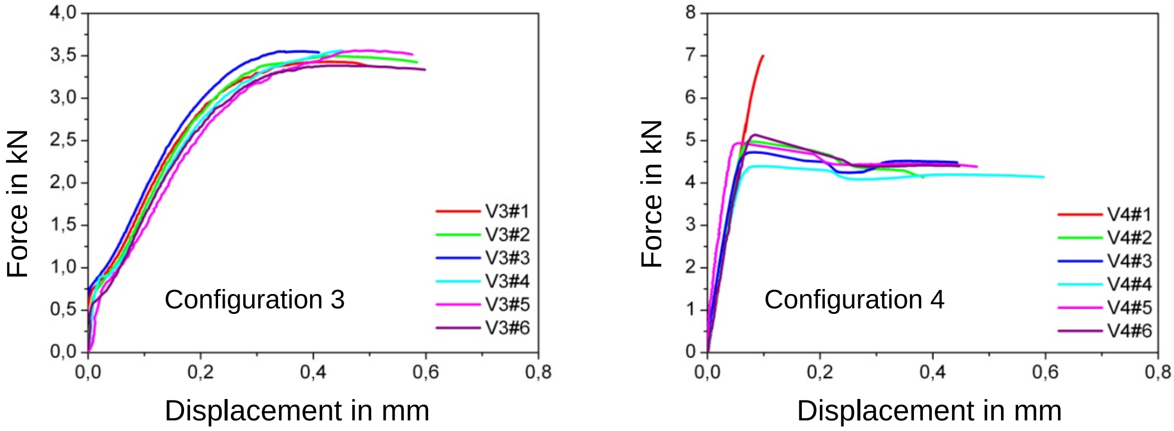


Figure 2. Results of pull-out tests with PA6.6 GF40 and steel with four different joint configurations

3 Modeling approach

The experimental results show that an appropriate modeling approach has to take into account different acting joining mechanisms.

Force fit: Due to the shrinkage of the polymer during fabrication the hybrid specimen exhibits residual stresses which result in a force fit between the LFT and the metal. For metal inlays which are surrounded by LFT the force fit is always present. In order to model the other joining mechanisms correctly the exact force fit has to be included in the models.

Direct adhesion: After pre-treatment of the metal surface the polymer of the LFT can act as an adhesive. Thus, the LFT and the metal are glued together and the LFT is the adhesive and one joining partner at the same time. The modeling can be performed similar to the modeling of adhesive joints.

Form fit: In the manufacturing process the LFT flows through the hole and a form fit similar to a bolt or rivet is established. In this case the LFT is one joining partner and the bolt at the same time. Due to the fact that here the LFT is loaded up to its failure it has to be modeled properly in order to predict the mechanical properties of the form fit.

All finite element simulations were performed with Abaqus 6.11 Standard. The pull-out specimens were modeled as a quarter. Volume elements were used. The mesh is shown in Figure 3.

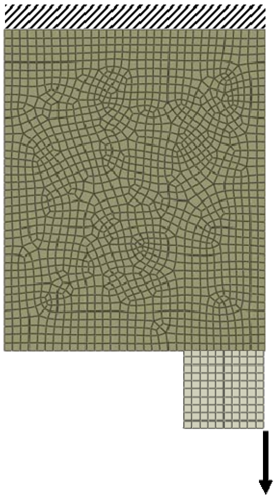


Figure 3. Finite element model of the pull-out specimen

3.1 Force fit

In order to model the force transmission based on force fit two things have to be taken into account in the model, the residual stresses in the hybrid part due to the shrinkage of the polymer and the friction behavior between the steel and the LFT. The residual stresses were applied in the model via an additional calculation step. A negative temperature load is applied to the model and due to the different coefficients of thermal expansion of LFT and metal residual stresses are introduced. In the following next step the pull-out test was modeled. The friction was implemented using a simple friction model based on Coulomb's law. The friction coefficient was assumed based on literature data [7]. For the rough metal surface the coefficient was chosen as $\mu = 0,6$ and for the untreated surface as $\mu = 0,3$. The temperature difference of the first step was chosen in order to fit the experimental data. In Figure 4 (left) force displacement curves of pull-out tests with the blasted metal surface in which the metal inlay is pulled out completely are shown. The simulation results fit well with the experimental results. For the untreated surface tests with a complete pull-out are not available therefore the results can be compared only at the beginning of the curve. In order to verify the model pull-out tests with a longer metal inlay were tested and simulated. The results are shown in Figure 4 (right).

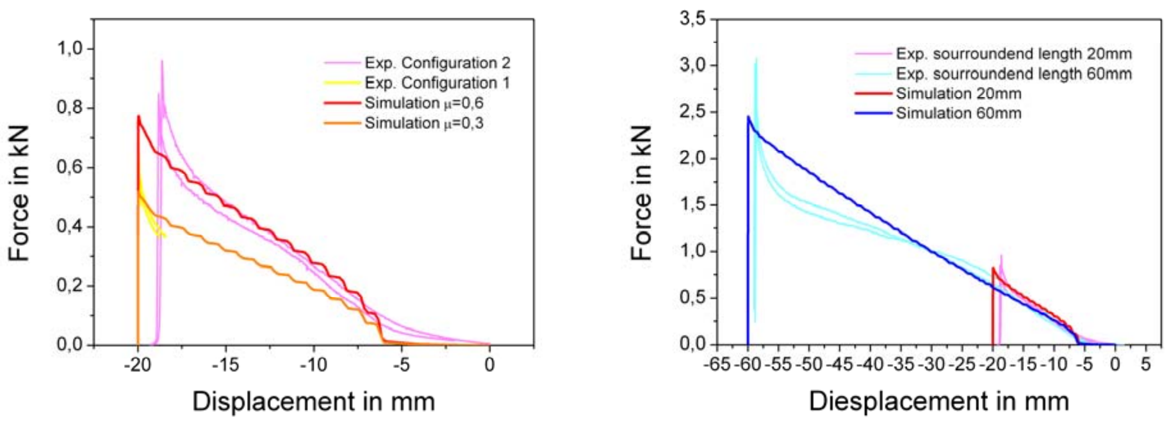


Figure 4. Experimental and simulation results of pull out tests characterizing the form fit

1.1 Direct adhesion

The direct adhesion was modeled applying a cohesive zone approach. To be able to model the force fit and the direct adhesion simultaneously surface based cohesive properties were defined. Abaqus offers the possibility to define a traction-seperation behavior for contacts in between two different parts. This cohesive behavior is very similar to the behavior of cohesive elements which are often used for the simulation of delamination in composites or the failure of adhesive joints.

In order to find the appropriate input data for the damage initiation simulations including the force fit and the direct adhesion were performed and the damage parameter was modified such that the results of the simulation fits the experimental results. The comparison of the experimental and numerical results are shown in Figure 5 (left). To verify the modeling approach a simulation with the same input data but with a longer metal inlay was performed. Figure 5 (right) shows that simulation of the longer specimen is in good agreement with the experimental results. Since it is not possible to perform tests for the identification of damage evolution parameters those had to be estimated.

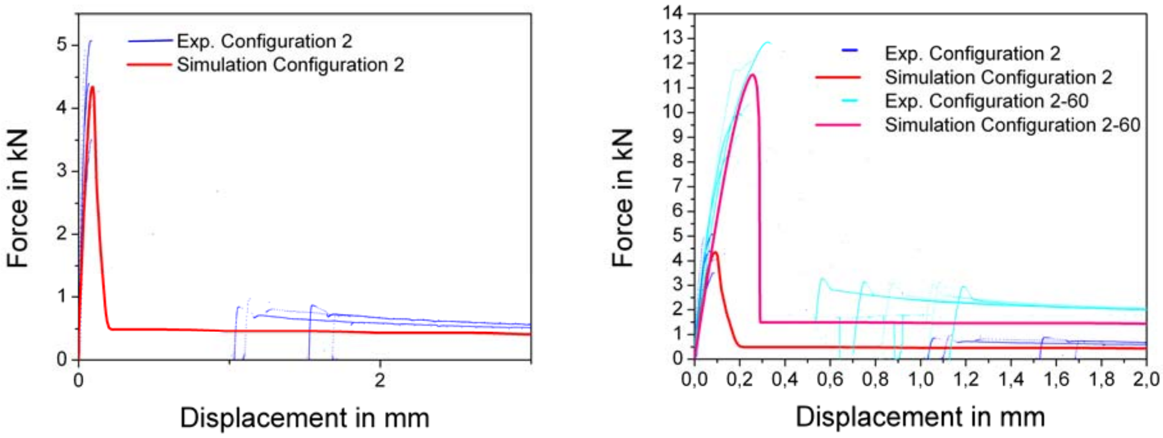


Figure 5. Experimental and simulation results of pull out tests characterizing direct adhesion

1.2 Form fit

For an evaluation of the load carrying capacities of the form fit the mechanical behavior of the LFT has to be modeled properly. The LFT exhibits a nonlinear anisotropic material behavior [8]. In Abaqus there is no material model available which is able to describe the anisotropic plasticity and the tension and compression anisotropy. For the failure of the form fit the shear behavior is the dominant material property. Therefore the material is modeled with an anisotropic elastic plastic material model using Hill plasticity [9] which is implemented in Abaqus. Damage is modeled with a strain based failure criterion. Since it is not possible to experimentally determine shear data with the fiber orientation which was found in the form fit shear data was fitted to the experimental results of the pull out test. The results of a simulation including the force fit and the form fit is shown in Figure 6 (left). In order to verify the used material data a metal inlay with two holes was tested and simulated Figure 6 (right).

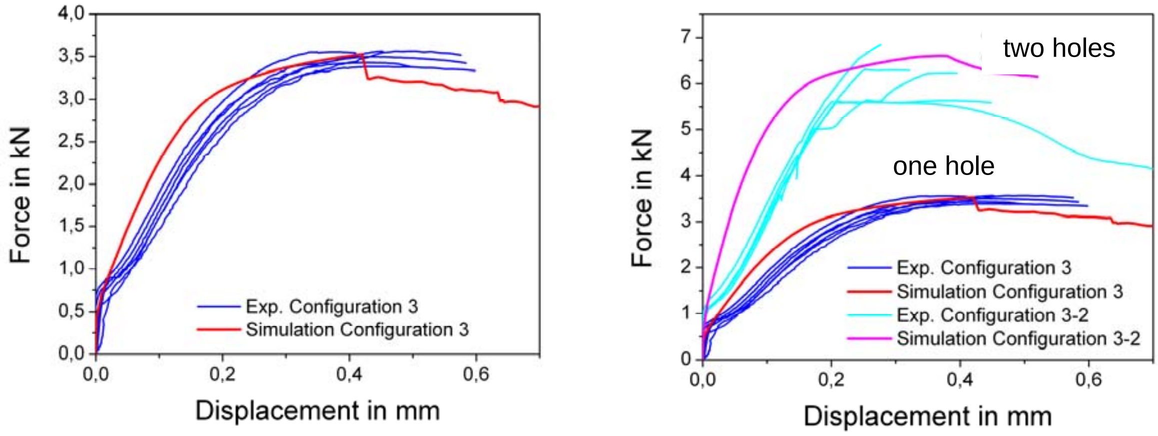


Figure 6. Experimental and simulation results of pull out test characterizing the form fit

5 Combination of joining mechanisms

One of the goals of the finite element modeling is the possibility to simulate different joint configurations such as the combination of direct adhesion with a form fit. In Figure 7 the results of experiments and a simulation related to such a configuration are depicted. The comparison shows that although the maximum load level is underestimated the simulated force-displacement curve is in good agreement with the experimental data.
A reason for the underestimation of the maximum load level can be an incorrect assumption of the damage evaluation parameter of the direct adhesion used in the simulation. Another reason can be scatter in the experimental results due to differing manufacturing conditions.

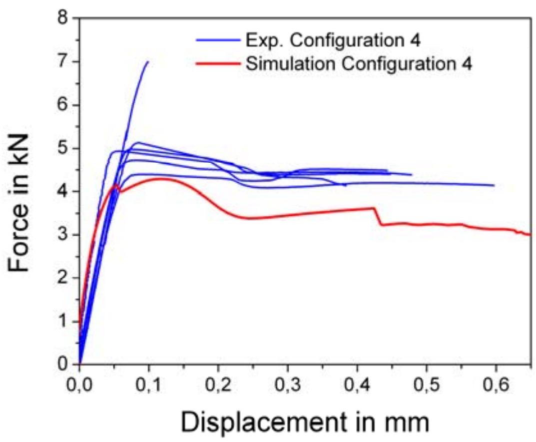


Figure 7. Experimental and simulation results of pull out tests with a joint configuration including direct adhesion and form fit

6 Conclusions and Outlook

A modeling approach for the joints of long fiber reinforced polymer metal hybrid is presented which is based on experimental results showing that the different deformation and damage behavior of the joint configurations is based on three different joining mechanisms: force fit, direct adhesion and form fit. In order to evaluate the mechanical behavior of the long fiber reinforced polymer metal hybrid joints, a modeling approach was developed in which the three mechanisms are modeled separately. For the force fit and the direct adhesion a contact

formulation with friction and a cohesive zone damage model was used. For the form fit the nonlinear shear deformation and damage had to be modeled. This was done using Hill's plasticity and a strain based failure criterion. The simulation results show that with the presented approach each single mechanism and their combination can be modeled.
In order to evaluate the influence of certain parameters numerical studies in which estimated parameters or values are changed according to their experimentally determined scatter will be performed. One of the studies will be the investigation of the influence of the estimated damage evolution parameter of the direct adhesion with regard to the configuration with form fit and direct adhesion.
In the next step other configuration and combinations of the hybrid joints will be modeled. One goal is to analyze the potential of different configurations for the application in structural parts.

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