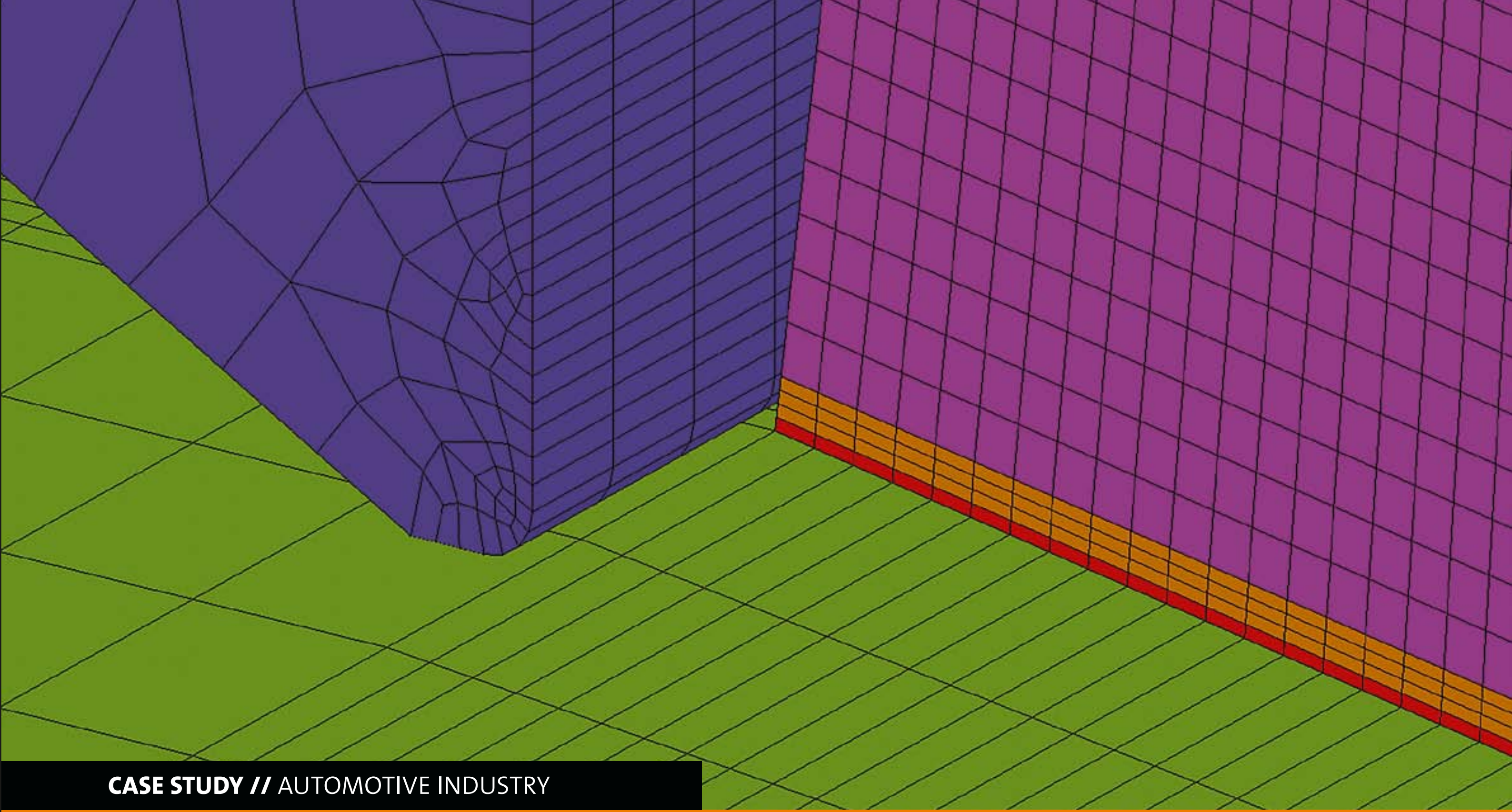

CASE STUDY // AUTOMOTIVE INDUSTRY

SHEAR TESTS FOR AUTOMOTIVE ELECTRONICS

Conducting a Finite Element simulation and parameter identification, optiSLang and multiPlas are used for tests in the automotive industry to identify the shear and tensile strength parameters of the interface between mold compound and copper substrate.

Optimization task

The goal of the documented analysis was the buildup of an appropriate mechanical model and the parameter identification for the shear button test carried out at Bosch. The test has been performed at different hammer positions in order to identify the shear and tensile strength parameters of the interface between mold compound and copper substrate. For this purpose, nonlinear mechanical analyses with incremental loading up to the ultimate failure of the system were carried out.

To simulate the delamination of the interface as well as the cracking of the mold compound, the material library multiPlas was applied that uses multi-surface plasticity models at continuum element level. Besides the failure mechanisms of the interface, it was necessary to include the crack properties of the mold compound in the simulation model. The main reason was the appearance of a compression force component during the shear test that causes a high shear resistance of the interface and finally leads to failure of the mold compound. In other words, the shear test is not only a test of the interface strength, but rather a test of the mechanical strength of the mold compound. In addition, the contact modeling at the hammer tip has been found as a key factor for a successful identification of the model parameters. Other than expected this is especially true for the high hammer positions and can be explained by a local stress resp. a local contact problem. Here, the strength properties of the mold compound also play an important role. Finally, a parameter set has been identified that allows for the fitting of all test shear forces. The fit parameters have been found to be very sensitive to changes especially of the contact model and the mesh density.

Goal of the analysis

The objective of the analysis performed is the identification of the model parameter for the recalculation of the delamination process between mold compound and Cu-substrate during the button shear test.

For this purpose the following data are available:

- geometric parameter of Cu-substrate, mold compound cone and shear hammer
- maximum shear forces and corresponding displacements for 10 different hammer positions at room temperature

and corresponding failure images showing the interface after the debonding of the mold compound from the Cu-substrate

The following questions are investigated:
- recalculation of the shear test at all available hammer positions
- identifying the failure mechanisms at the different hammer positions
- sensitivities of the interface parameter on the calculated shear forces
- identification of the material data which allow for the fitting of the maximum shear forces at low and high hammer positions.

The complexity of the developed model requires a large computational effort to calculate the failure load of the system and therefore the parameter identification was carried out by applying the Meta Model of Optimal Prognosis (MOP) feature of the optiSLang software. The identified data set was then recalculated by FEM to ensure the quality of the MOP. It has been found that the remaining difference between the solution based on the MOP and the FEM is within a ± 10% band width.

Simulation Model

Figure 1 gives an overview of the structure. The structure has been analyzed by applying symmetry conditions in the XZ-plane and therefore in all figures only 1/2 of the model (Cu-substrate, mold compound and hammer) is shown. In Figure 2, exemplary two positions (lowest and highest) of the steel hammer are shown. From Figure 3, the detailed layered structure of the model can be seen. The red layer models the interface between Cu-substrate and mold compound (multiPlas – anisotropic joint with Mohr-Coulomb frictional law and softening). On top of the interface layer, three mold compound layers are assigned to an isotropic Mohr-Coulomb material (multiPlas – ideal plastic multi-layer joint) in order to model the fracture of the mold compound close to the interface. The applied Mohr-Coulomb material description of the interface is shown in principal in Figure 4. Figure 5 shows a typical shear stress distribution after initiation of the delamination process for one specific hammer position. The highest shear stresses appear at the location of the highest compressive stresses according to the applied Mohr-Coulomb frictional law.

Sensitivity Analysis

A sensitivity analysis was carried out with optiSLang to understand the main effects and most important parameters for the parameter identification. The input parameters are fi (friction angle), coh (cohesion), ft (tensile strength), GI_fac (mode I fracture energy factor) and GII_fac (mode II fracture energy factor) of the interface material layer as well as cntfric (contact friction between shear hammer and

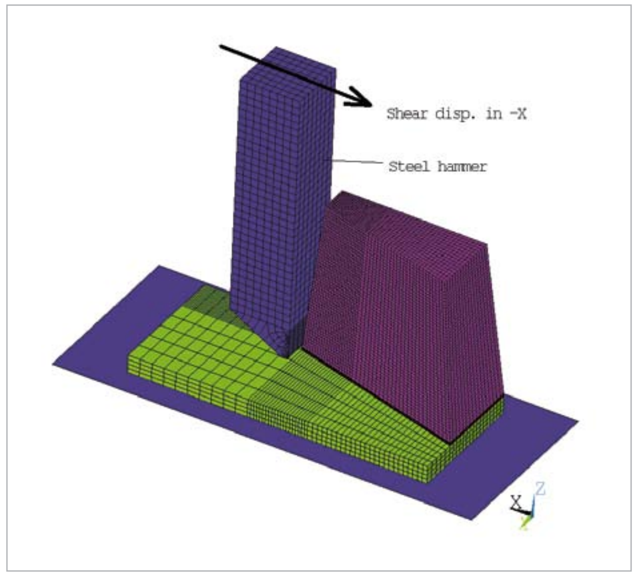

Fig. 1: Steel hammer with shearing direction

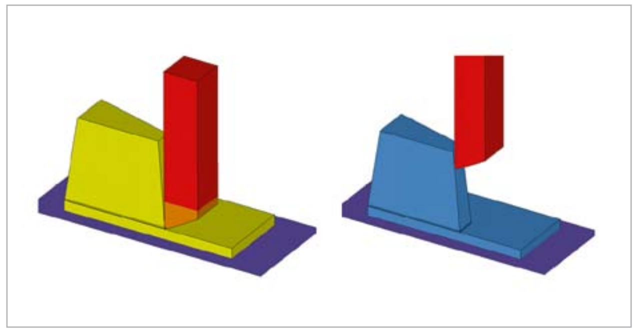

Fig. 2: Lowest and highest hammer position

mold compound cone) and cnttmax (maximum contact shear stress between hammer and mold compound). The outputs are the maximum shear forces and corresponding displacements at all different hammer positions.

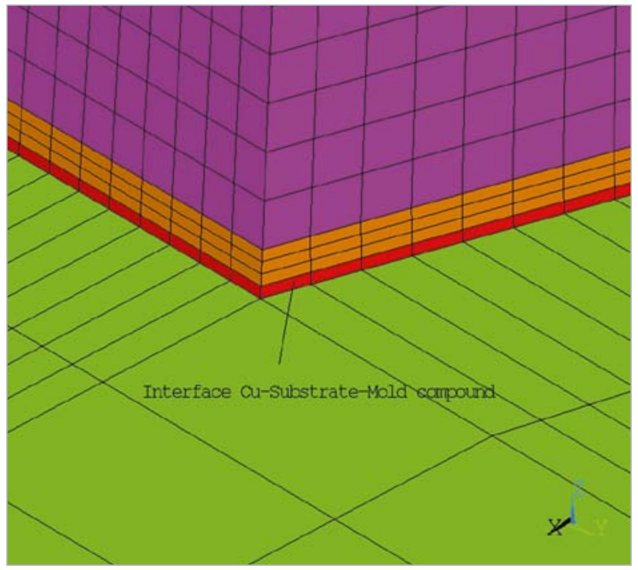

Fig. 3: Interface layer (cohesive zone)

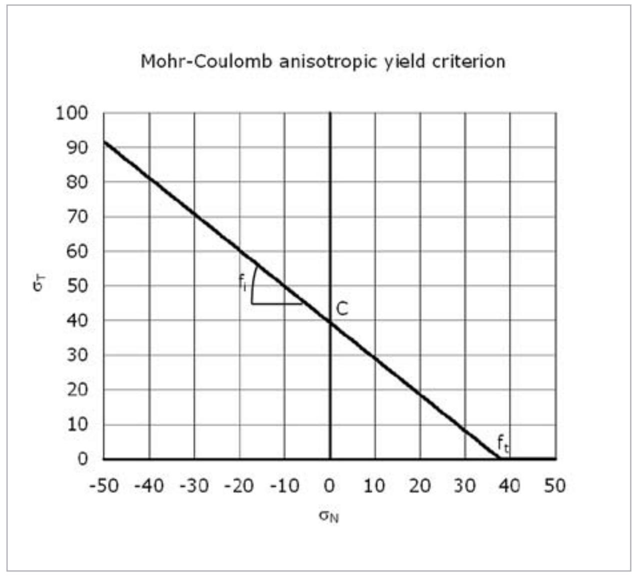

Fig. 4: Mohr-Coulomb frictional law (multiPlas Mat #120)

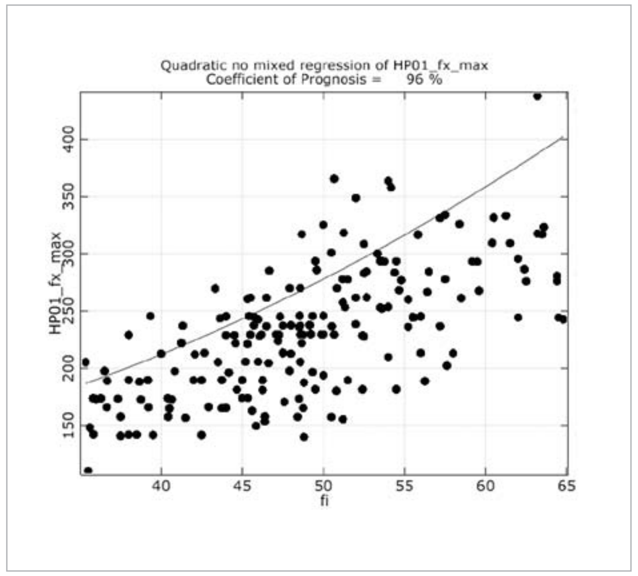

Fig. 7: Anthill plot – lowest hammer position

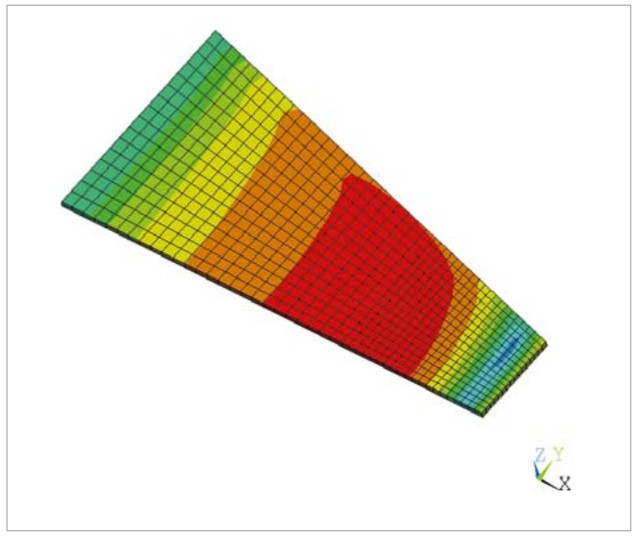

Fig. 5: Shear stress distribution in the interface layer

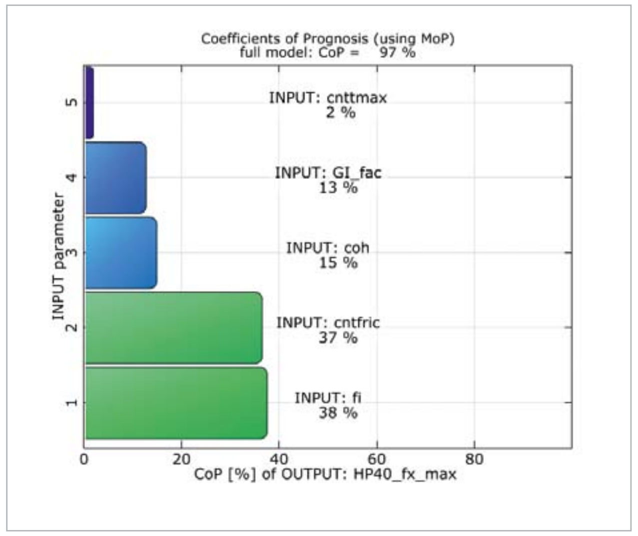

Figure 8: Coefficients of prognosis – highest hammer position

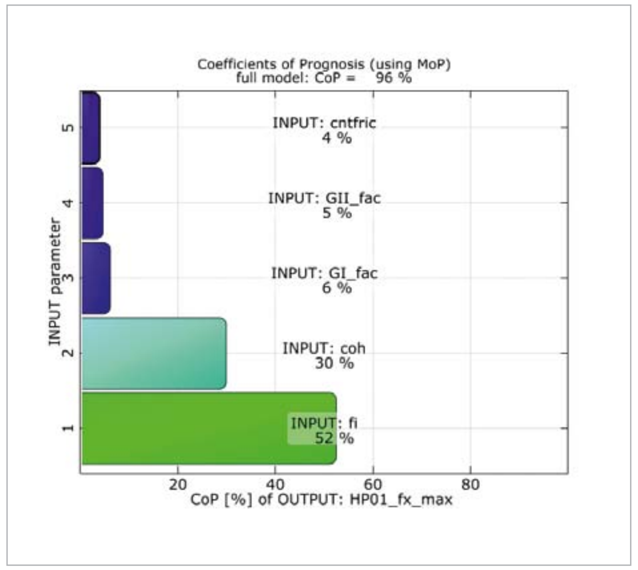

Fig. 6: Coefficients of prognosis – lowest hammer position

It has been found that at low and high hammer positions different parameters are of importance and complex mixed term regression models are needed to describe the systems behavior. In Figure 6 and Figure 8, the important parameters with their Coefficients of Prognosis (CoP) are shown for the lowest and highest hammer position. As an example, the Anthill plot of friction angle and maximum shear force at the lowest hammer position is shown in Figure 7. The MOP is based on 200 Latin Hyper Cube samples and total CoP values larger than 95% enable the use of the Meta Model in later optimization or identification tasks.

Parameter Identification

The identification of a unique parameter set which fits the simulation results to the experimental data for all different hammer positions has been performed by using the MOP-

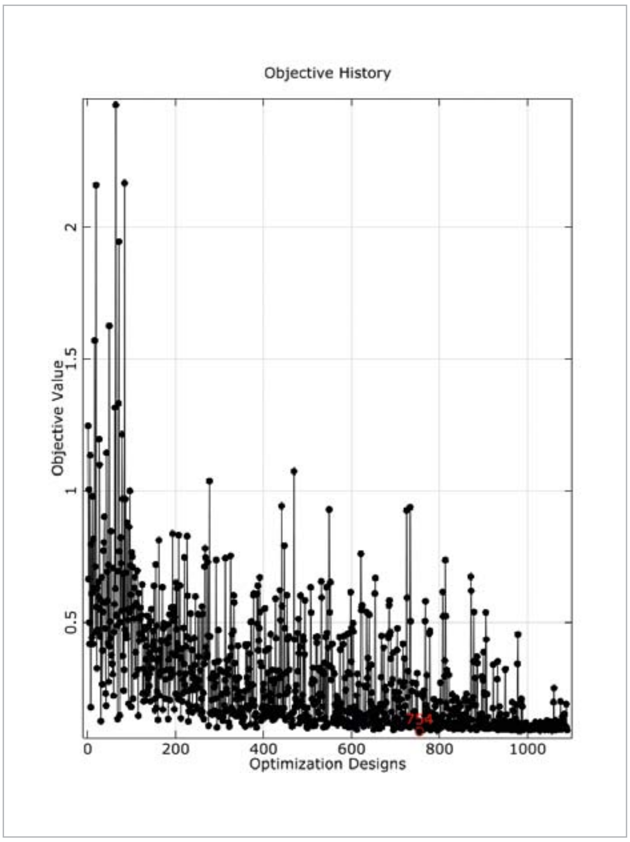

Fig. 9: Objective history global search

solver calls are used which require several hours or even days instead of a few seconds required by the MOP-Solver to approximate the solution based on a Meta model.

Figure 10 shows the comparison of the test and the simulation data. In addition, the recalculated results of a few designs by direct FEM-Solver calls are plotted in Figure 10. It has been found that the difference is about +/- 10% compared to the MOP-Solver approximation.

Conclusions

A finite element model has been developed that allows for the recalculation of all hammer positions in terms of maximum shear force Fmax and displacement Umax using a unique set of material data for the button shear test. This could be achieved by applying the material library multiPlas for the interface and mold compound material to take into account multi-surface plasticity constitutive laws (anisotropic and isotropic Mohr-Coulomb and Drucker-Prager yield criterion). The Meta Model of optimal Prognosis (MOP) has been used to identify the important parameters and to fit the simulation model to the shear test data. This approach has been found to be most suitable for such noisy and time consuming non-linear simulation models.

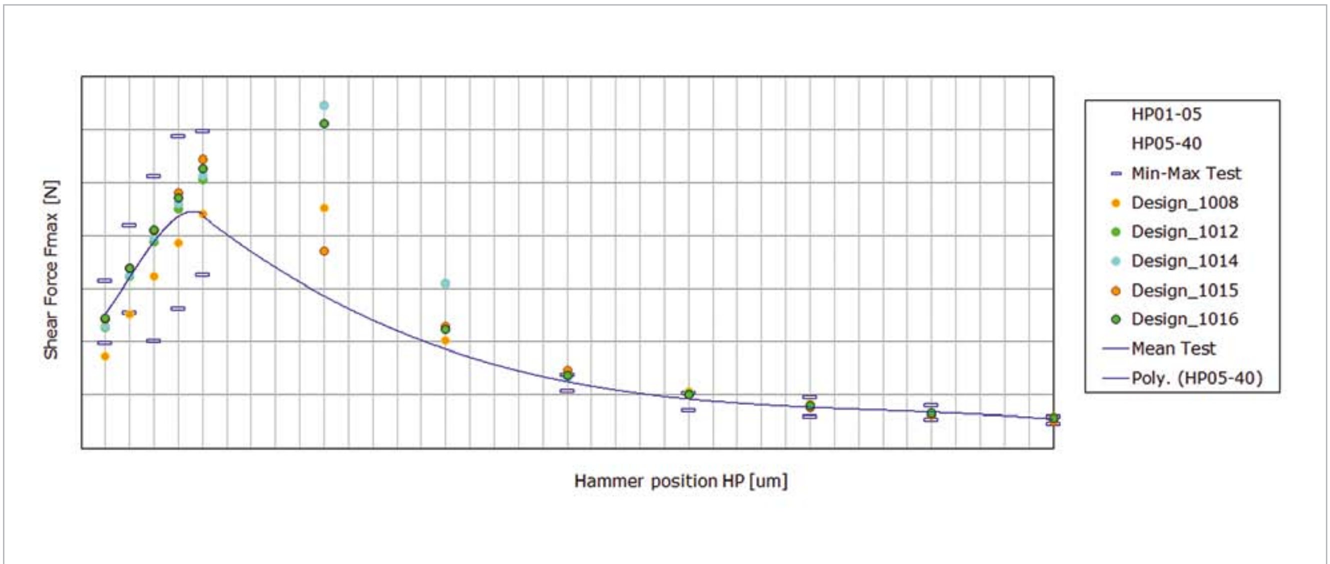

Fig. 10: Comparison of simulation and test results

Solver of optiSLang. Therefore no direct solver calls are necessary during the identification and the solvers noise resulting from the non-linear limit load calculation is smoothed out by the response surface approximation.
As optimization procedure a global evolutionary algorithm has been applied to avoid the convergence to local optima which fit only to specific hammer positions. In Figure 9 the history of this global search with more than 1000 realizations is shown. Of course this wouldn't be possible if direct

In general, it has to be mentioned that the Meta model itself (the response surface) is very complex due to the brittle softening of the materials and requires at least 200 DOE samples. Otherwise the nonlinear correlations of strength and energy parameters cannot be identified.

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