

CASE STUDY // MECHANICAL ENGINEERING

AUTOMATIC CALIBRATION OF SUBSTITUTE LOADS TO ESTIMATE THE IMPACT OF JOINING DISTORTION

optiSLang optimizes the process of model calibration by automatic identification of suitable input and output parameters for a realistic impact prognosis of joining distortion on the deformation of parts in the assembly.

Introduction

Due to the rising possibilities of the Finite Element Method (FEM) regarding virtual tolerance prognosis, it is also increasingly used in Car-Body-Production. Among others, one application is to simulate the distortion caused by the up to 6,000 joining operations during car manufacturing. However, the calculation of deformations related to joining procedures, as well as the integration of detailed FE-models for joints into full car models would result in prohibitive simulation time. As a solution, simplified model approaches for joints are necessary. The idea behind these simplified approaches is to use mechanical loads to estimate the deformation brought about by joining processes in the FEM. At present, adequate surrogate loads for mapping joining distortion are often still derived in a manual calibration process which consumes a lot of time and effort.

One approach is using the optimization software optiSLang for the automatic calibration of surrogate mechanical loads. The article will show how the tool can be applied to properly derive suitable input and output parameters, to generate a target function and to develop methods of optimization with the help of a real-life joining situation.

Customer's requirements regarding the quality of the car's impression cause a constant reduction of gap dimensions and tolerances. At the same time, using more and more lightweight materials, such as higher-strength steel, makes the manufacturing process for component parts and assemblies increasingly complex. The automotive industry uses more and more simulation tools based upon the FE method to meet these challenges. Thus, for example, the joining of car bodies can be simulated in an early phase of the manufacturing process.

Here, the potential of FE based simulation will particularly be shown in using a surrogate mechanical model to numerically predict the impact of the joining process on the deformation of parts in the assembly. The basic idea is to simulate the geometrical deformations resulting from the joining process with the help of locally induced mechanical loads. These loads have to be calibrated in advance using simplified experimental reference setups. During this process, the following steps for substitute modeling of joining distortion have to be considered (see Fig.1):

1. Derive a simplified reference assembly from a car body structure
2. Join the reference assembly and determine the deformation experimentally
3. Calibrate the substitute mechanical loads for a substitute model build on a local level using the experimental data
4. Transfer the resulting substitute loads of the substitute model to the joint model of the complex car body structure
5. Use an elastic FE calculation to determine the global component part distortion

The aim here is to replicate the distortion shapes of the simplified process model. Thus, the calibrated substitute mechanical loads transferred to the global component part structure result in approximately the same state of deformation as seen in reality. The quality of model calibration (i.e. the capability of the simulation model to map the experimental reference) is crucial for the quality of the substitute mechanical model. Using a manual process, a high level of personal effort is necessary to produce a reasonable mapping quality. With complex calibration models, this iterative analytical process can take several days. In the future, the calibration process can be supported by methods of CAE-based optimization to automatically generate a high quality level of responding substitute mechanical loads for mapping. As Fig. 2 (see next page) shows, the software optiSLang was integrated in the calibration process with the objective to decrease time and effort needed for calibrating substitute mechanical models. Here, a reduction from several days to a maximum of four hours could be achieved.

Simulation method

The FE program PAM-STAMP 2G (ESI group) was used for simulative mapping of the joining process. As the schematic example of a spot-welded joint shows (Fig. 3, see next page), the modeling of the joining process can be reduced to the following simulation steps:

1. Positioning and clamping of the specific components
2. Connecting the joining components with rigid girder elements at the position of the electrodes
3. Use of mapping to implement substitute mechanical loads in the form of tensions (stress) in the area of the joining point
4. Calculating the balance where a change in the geometry has a result on the component parts

Parameter identification

Input parameters

2-D shell elements are used to make the parts to be joined discrete in the FE model, reaching a conformity with the Belytschko-Tsay element formulation. These shell elements are mostly used in the sheet metal forming simulation and describe the behavior up to five integration levels above the virtual sheet thickness. The specific integration levels of the shell elements are mapped with the stress deposited in the mapping file during the mapping procedure as depicted in Fig. 3 (see next page, refer to Step 3). Thus, the distortion measured in Point 2 in Fig.1 was reached. This enables the

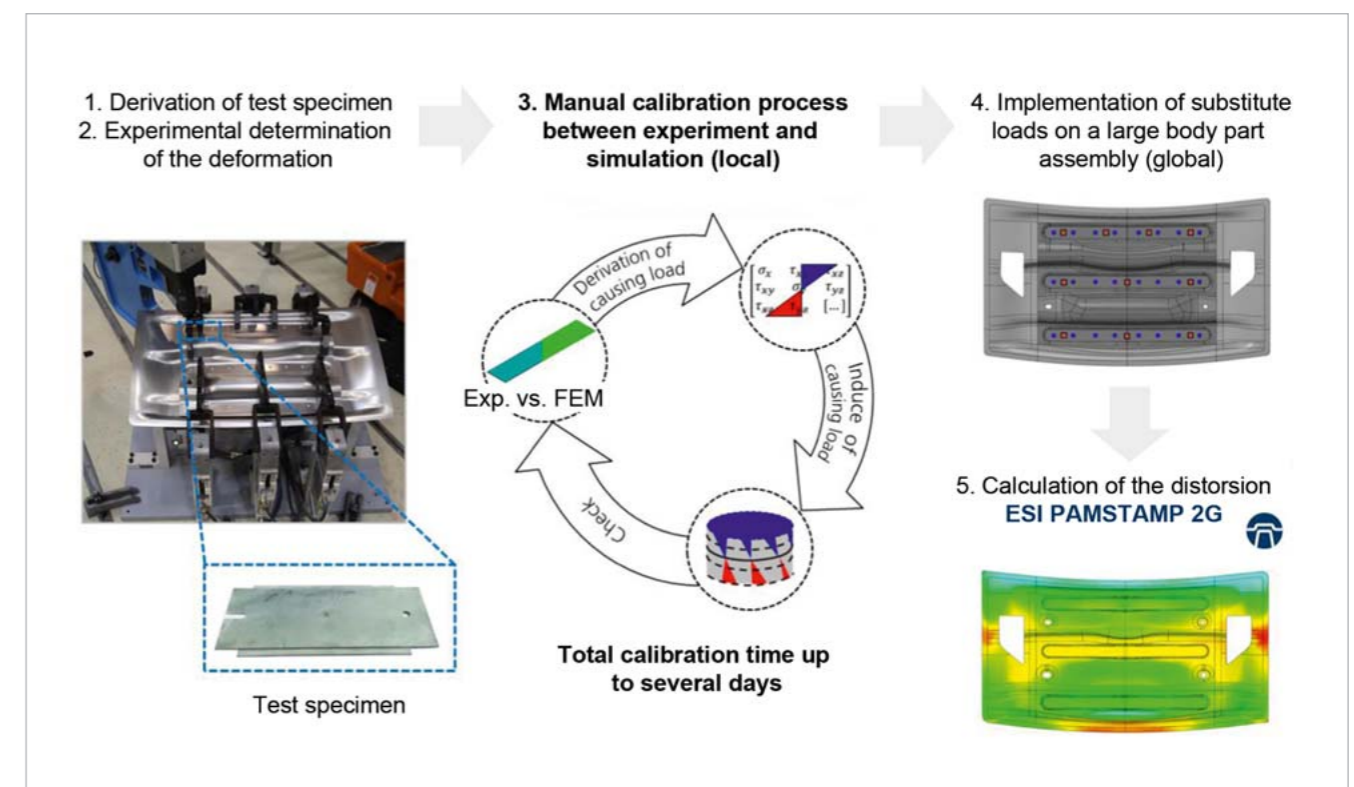


Fig. 1: Manual calibration process for substitute mechanical models

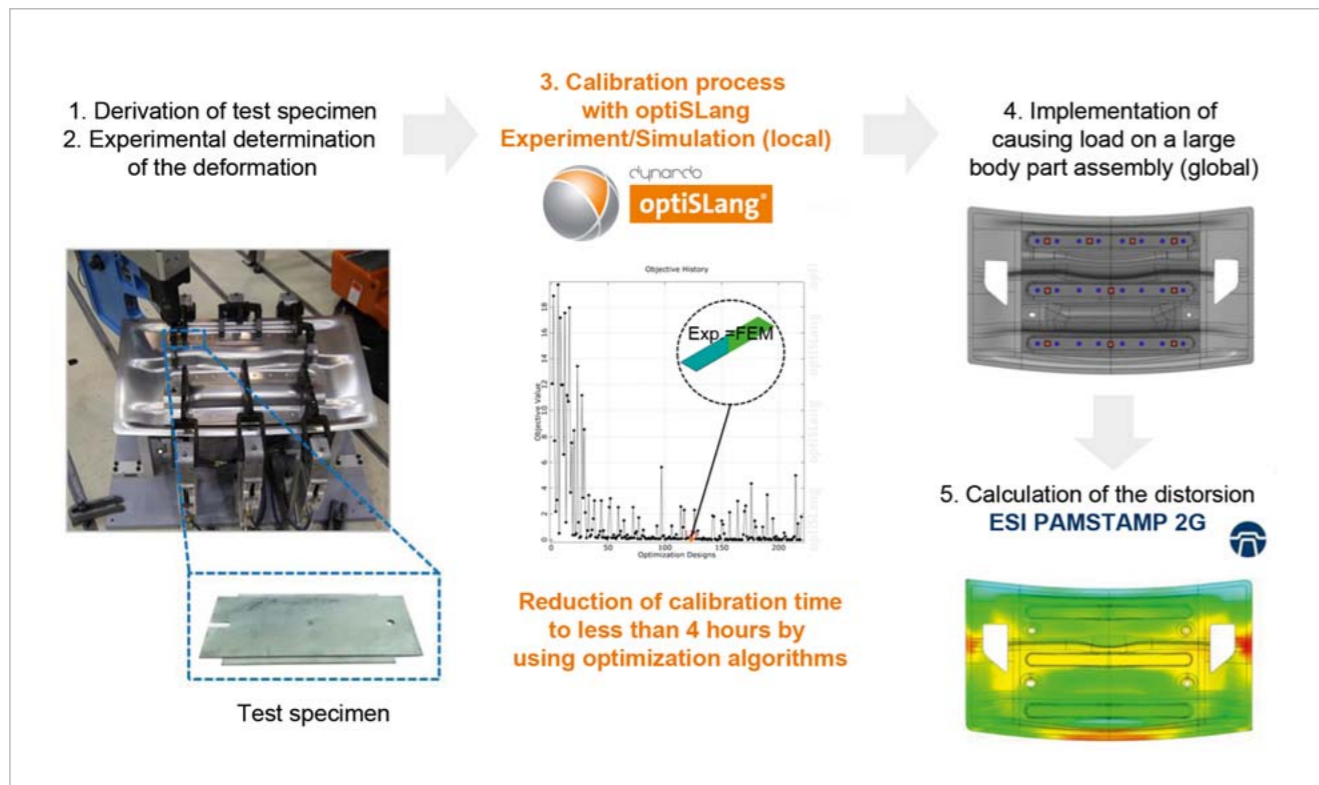


Fig. 2: Integration of optiSLang into the calibration process

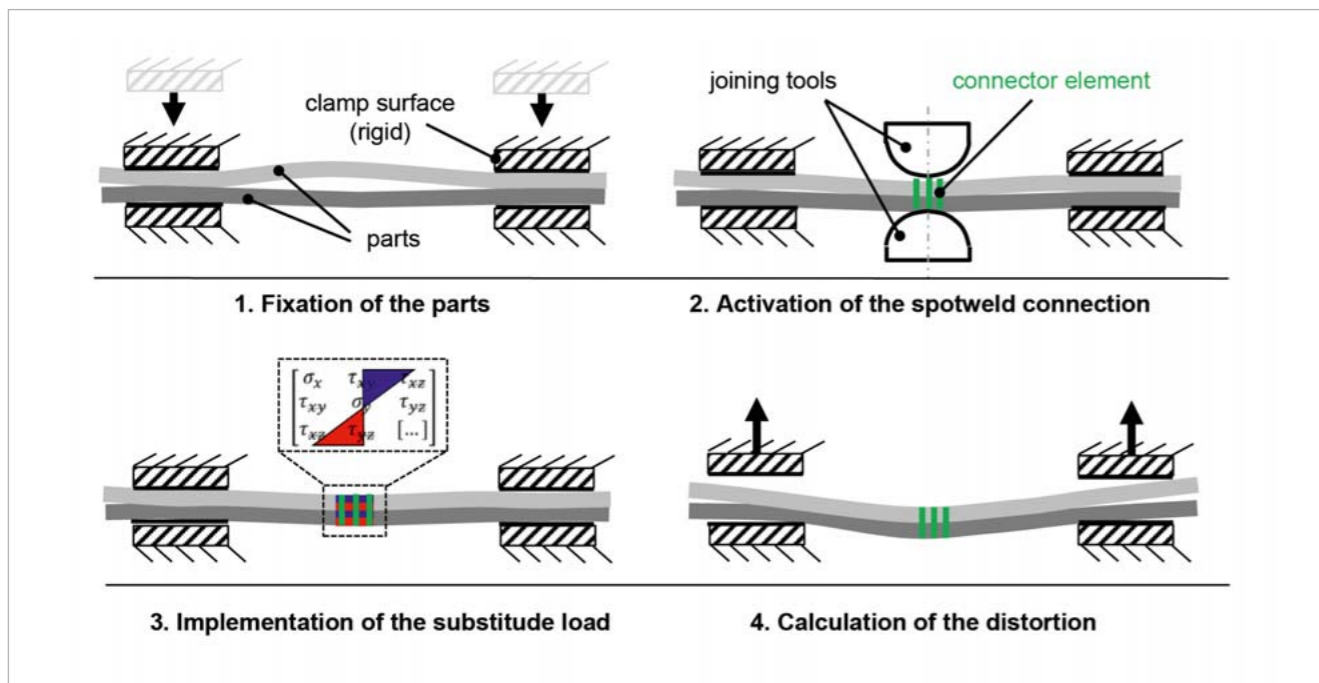


Fig. 3: simulation steps to compute the joining process

user to have control over the intensity of distortion in regard to the simulation model. Therefore, the fundamental idea is using optiSLang to access needed stress defined in the mapping file and to use an optimizing algorithm to systematically modify them. So, the simulation model comes closest to the experimental reference during the calibration processes.

Because both the upper and lower blanks were independently mapped with substitute mechanical loads, a total of ten input parameters for optimization (see Table 1) were produced. The derived input quantities that were supposed to describe the behavior of the shell's cross-section mathematically are shown in Fig. 4. Furthermore, the parametrized stress from the optimization algorithm could be continuously varied for

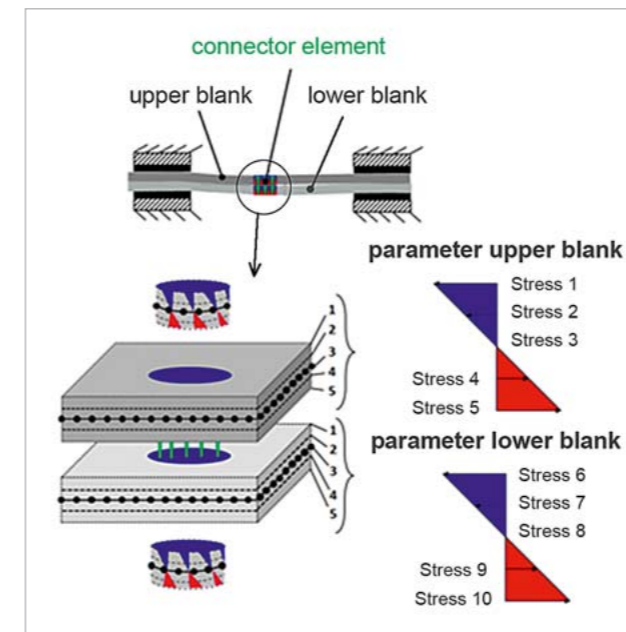


Fig. 4: Identification of the parameters on the 2-D shell element

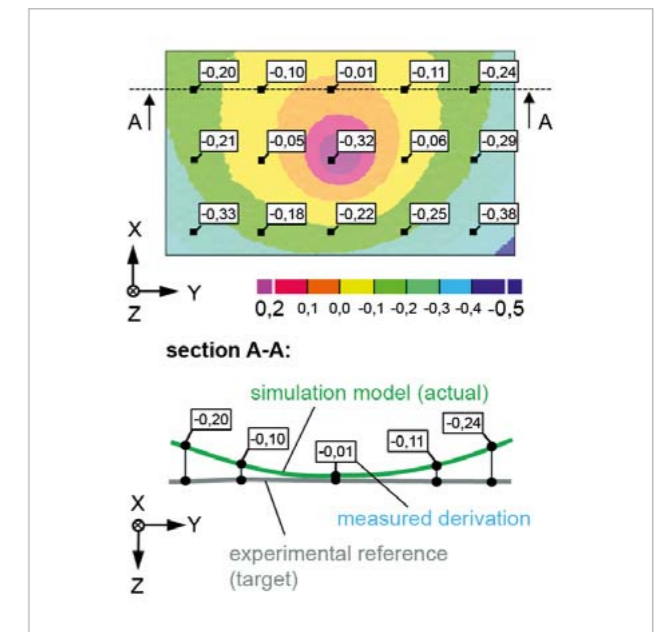


Fig. 5: Definition of objective

No	Parameters	Lower Bound	Upper Bound	No	Parameters	Lower Bound	Upper Bound
1	Stress1_Oberblech	-10 MPa	10 MPa	6	Stress1_Unterblech	-10 MPa	10 MPa
2	Stress2_Oberblech	-10 MPa	10 MPa	7	Stress2_Unterblech	-10 MPa	10 MPa
3	Stress3_Oberblech	-10 MPa	10 MPa	8	Stress3_Unterblech	-10 MPa	10 MPa
4	Stress4_Oberblech	-10 MPa	10 MPa	9	Stress4_Unterblech	-10 MPa	10 MPa
5	Stress5_Oberblech	-10 MPa	10 MPa	10	Stress5_Unterblech	-10 MPa	10 MPa

Table 1: selected parameters and their variation limits

the upper and lower blank to search for the optimum design configuration where the pressure and tensile stresses can be assigned to the shell elements in the joining zone.

Objective criterion

Discrete measuring points were defined as targets on the entire surface of the assembly of the calibration model. This created the space in the Z-direction of the simulation model (ACTUAL) in regard to the experimental reference (TARGET) at the end of a simulation run-through. Fig. 5 shows the definition of the targets on the calibration model.

To be able to consider all of the measuring points, it is necessary to use a target function to combine the effective interrelationships discovered in an optimization model. The value of the target function was calculated from the total of the squared spaces between the experiment and simulation at the specific measuring points. The objective of optimization is to keep this function value as minimal as possible or, in other words, to minimize the amount of which the simulation model and the experimental reference differ from one another at all measuring points.

Case study

A real-life example of car body engineering was used for examining the functionality of the calibration procedure. It is described here by deriving two specimens from one complex car body structure: specimen no. 1, consisting of three joining points and specimen no. 2, consisting of five joining points (see next page, refer to Fig. 6). Specimen no. 1 was used to automatically calibrate the model with optiSLang while specimen no. 2 was used to check the quality of the calibrated substitute model for the second situation. Finally, any divergences between the experiment and simulation were calculated.

Calibration model: specimen no.1

Because of the small number of just ten parameters to be calibrated, the optimization was based on an adaptive response surface method (ARSM) implemented in optiSLang. The ARSM algorithm generates a support point pattern consisting of ten samples in every iteration step and shifts it until the algorithm reaches a user-defined termination criterion. In the case of this example, the termination criterion is met when either the optimizer reaches a maximum of 90 simulation runs, i.e. nine iterations, or the objective function shows

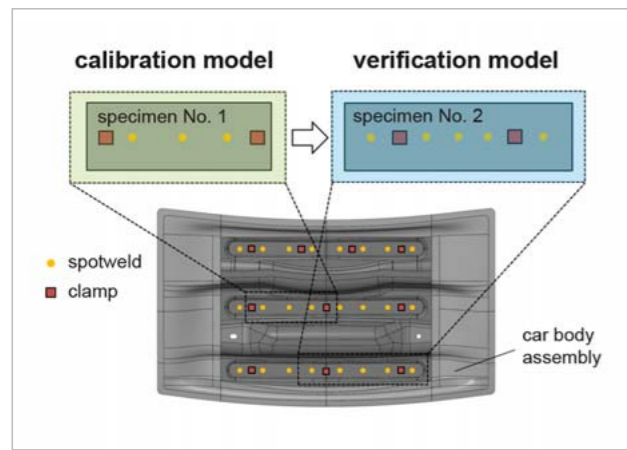


Fig. 6: Test specimens used during the test

a value smaller than 0,01. The convergence procedure of the ARSM could be derived from the objective history diagram shown in Fig. 7 (top) and the parameter history diagram for the parameter Unterblech_Stress5 in Fig. 7 (bottom). In this connection, the optimizer reliably converges after a total of nine iterations (90 simulations) and reduces the functional value of the target function to 1.2 in the first iteration loop and to the user defined stop criterion of approximately 0.033 in the final iteration step. Altogether, the optimization of the substitute loads required approximately three hours running four simulations simultaneously. Thus, the target of reducing the simulation time for the calibration process to less than four hours was reached without any problems.

The resulting deformation from both the experimental reference (blue) and the simulation (red) were referenced to the design state (CAD-0) for evaluating the quality of calibration. The welding distortion was evaluated along the cutting plane designated on the upper and lower blank in the sheet's normal direction (refer to Fig. 8).

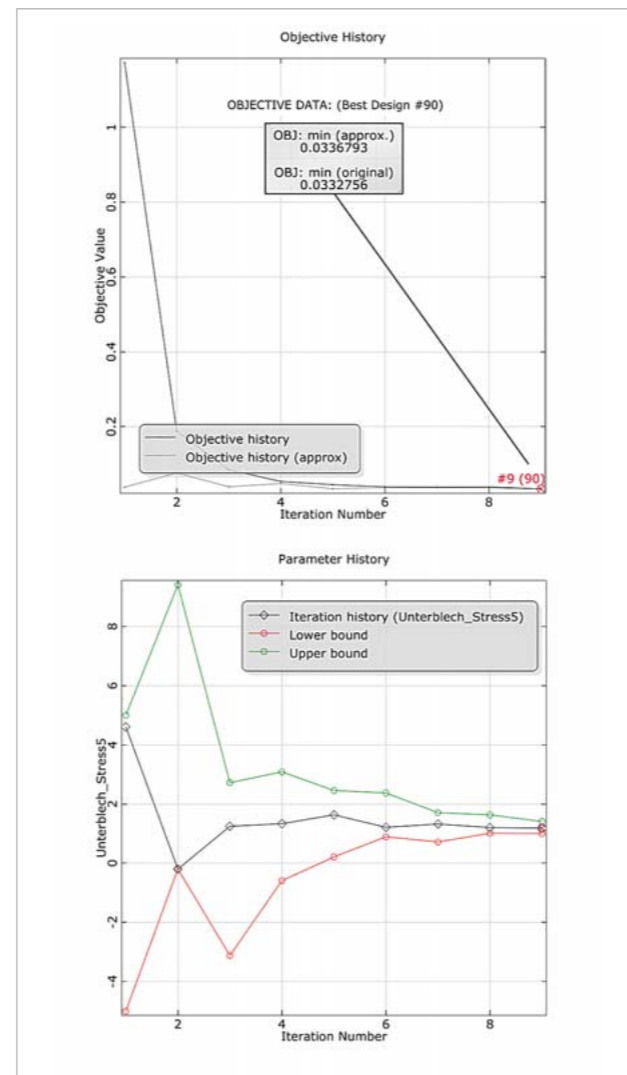


Fig. 7: The objective history diagram of the ARSM algorithm (left) and the parameter history diagram of the Parameter Unterblech_Stress5 (right)

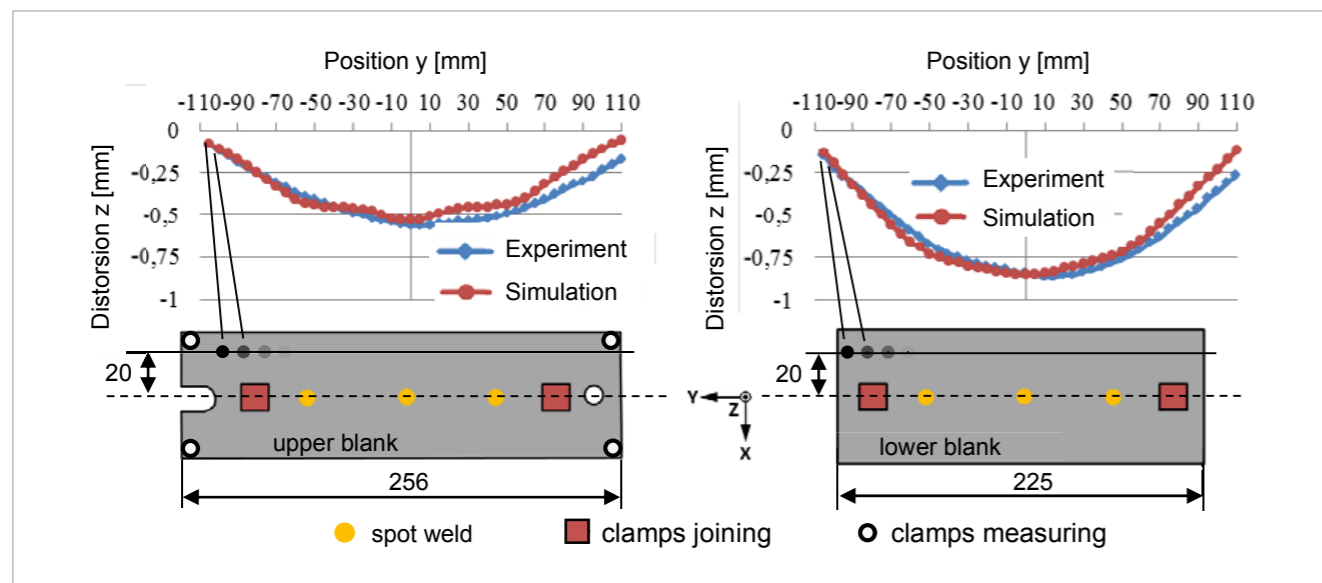


Fig. 8: Calibration results (Simulation vs. Experiment) for specimen no. 1

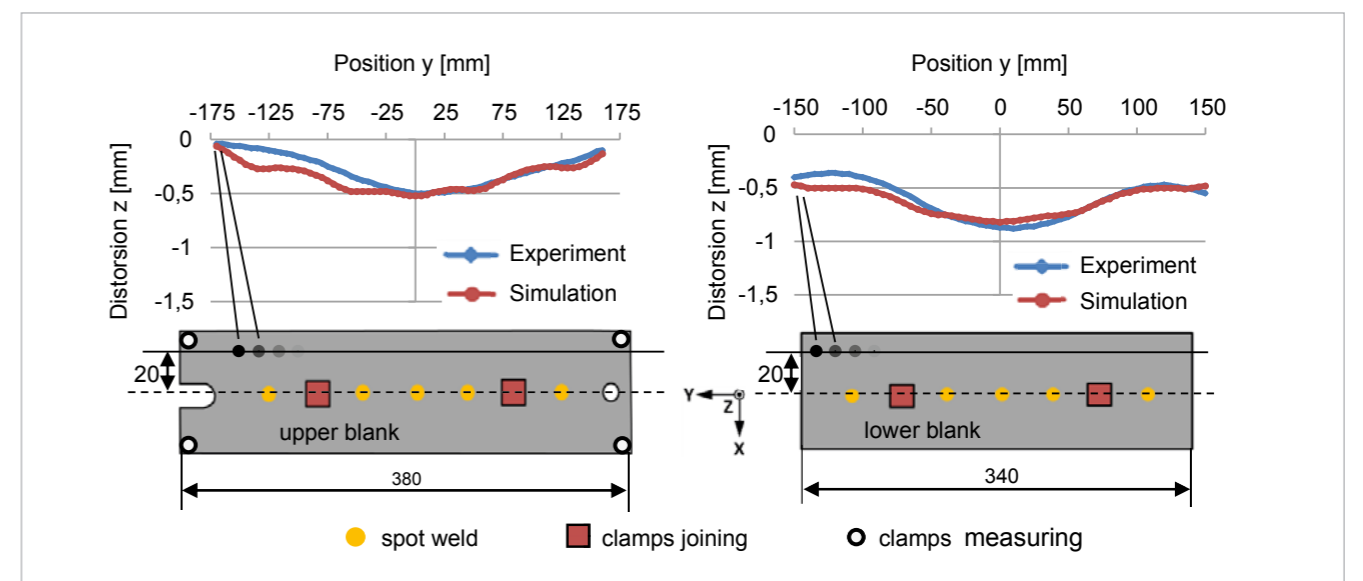


Fig. 9: Comparison of measured and simulated distortions of specimen No. 2 (Calibration model: specimen No. 1)

The prognosis of deviations in the simulation showed excellent agreement with the experimental data. Furthermore, the maximum difference of the distortion values from the simulation and experiment are less than 0.07 mm on both the upper and lower blank. From the calibration process of specimen no. 1, it can be concluded that the ARSM algorithm finds the matching configuration within a few iterations. Thus, the time and effort for identifying suitable substitute loads could be substantially reduced. The achieved calibrating quality was high in this example which indicates a proper suitability for further transferring of the substitute mechanical loads to more complex applications.

Verification model: specimen no.2

To verify the quality of results, the substitute loads calculated by the optimizer were transferred to specimen no.2 (five joining points) without any alteration. Fig. 9 shows the appropriate divergences between experiment and simulation.

The maximum deviation between the experiment and simulation is 0.05mm on the upper blank and 0.1mm on the lower blank. These matches indicate the high level of calibration quality of specimen no.1 making the substitute mechanical model capable of predicting reasonable distortions while being transferred to more complex applications.

Conclusion

An experience-based analytical process could be set up to exclusively calibrated substitute mechanical models. Without this procedure, surrogate mechanical loads, needed for matching the distortion, have to be manually calibrated. They were based on experimental iterations to the point where the joining distortion from experiment and simulation agreed. This requires not only a high level of user ex-

pertise, but also especially time-consuming change loops. Here, the potential of optimization-based model calibration could be demonstrated. The optimization algorithms decisively reduced time and effort for calibrating the substitute parameter to a couple of hours while maintaining a high level of calibration quality.

Author // Patrick Ackert, Christian Schwarz (Fraunhofer Institute for Machine Tools and Forming Technology)

Source // www.dynardo.de/en/library