Automatic Calibration of Substitute Mechanical Loads Using the Example of Joining Distortion

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Abstract

Due to the rising possibility of FEM for virtual tolerance prognoses, it is going to use more and more in Car-Body-Production. Besides other it is used to simulate the distortion done by the up to 6000 joining operations (Hu 2001) per car. Because calculating the joining related deformations and integration detailed FE-models for joints in full car models including the effect of joining in the deformation of the car parts would result in prohibitive simulation times simplified model approaches for joins 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 substitute loads for mapping joining distortion is still often derived in a manual calibration process consuming a lot of time and effort.

One approach to automatically calibrating substitute mechanical loads is shown in this publication where the optimizing program optiSLang (Dynardo GmbH) is used for calibration of the mechanical loads for substitute mechanical models. This will not only demonstrate the concept of automatic calibration and how suitable input and output parameters are derived, but, in addition to (Ackert 2015), also the used tools, the generated target function and more detailed the method of the optimization, developed using a real-life joining situation.

Keywords: Finite Element Method (FEM), joining process, distortion, simplified model, parameter identification.

1 Introduction

The customer's requirements made of the quality of the car's impression mean that the gap dimension is constantly being reduced while there is a constant reduction in tolerances (Bohn 1998). At the same time, using more and more lightweight materials such as higher-strength steel (Rohleder 2002) makes the manufacturing process for component parts and assemblies increasingly complex. The automotive industry counters this trend by using more and more simulation tools based upon the finite-element method (Gösling 2012) which makes it possible to use simulation of production processes early on in the phase of developing the tools and processes of car bodies such as the joining process.

The work of Neugebauer (2011), Eckert (2012), Neugebauer (2013), Eckert (2013) and Schützle (2015) demonstrate the potential of FE based simulation in complex car body engineering structure in the assembly process. In particular, these papers show how it is possible to use a substitute mechanical model to numerically predict the impact of the joining process on the deformation of parts in an assembly. The basic idea is to mimic the geometrical deformations resulting from the joining process with locally induced mechanical loads. These loads have to be calibrated experimentally beforehand using simplified experimental reference setups. During this process, there are the following steps for substitute modeling of joining distortion (ref. with Figure 1):

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

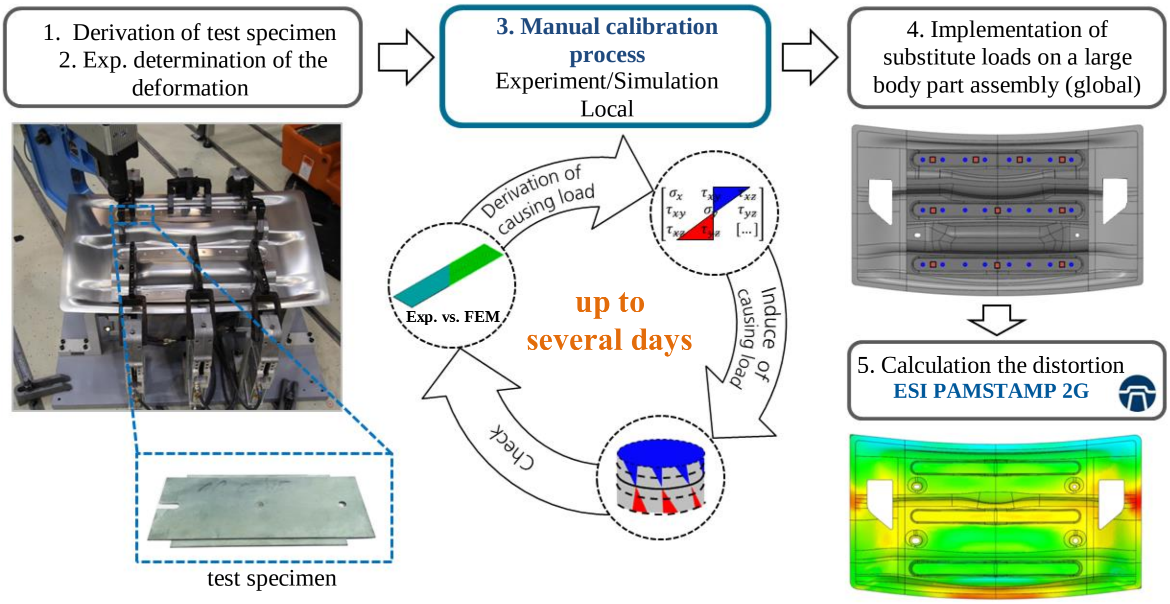

Figure 1: manual calibrating process for substitute mechanical models

The idea here is to replicate the distortion shapes of the simplified process model so that the calibrated substitute mechanical loads from transferring it to the global component part structure result in about the same state of deformation as seen in reality. Eckert (2012) states, that 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 there was a high level of personal effort necessary to result in reasonable mapping quality. With complex calibration models, this iterative analytical process can take several days. Furthermore, the effectiveness of optimization processes for identifying adequate process parameters has been documented in numerous simulative studies such by Will (2006), Schüler (2006) and Most (2015). In the future the calibration process should be supported by methods of CAE-based optimization to generate automated a high quality level of responding substitute mechanical loads for mapping. As Figure 2 shows, the optimizer tool optiSLang will be integrated into the calibration process with the objective of driving down the time and effort needed for calibrating substitute mechanical models from several days to a maximum of four hours.

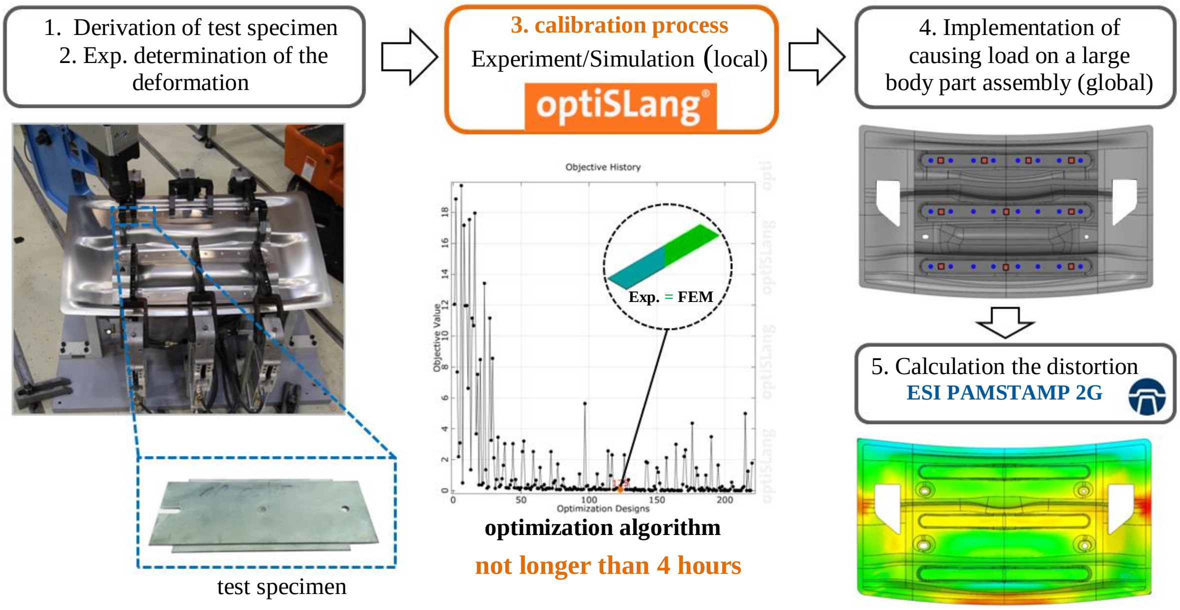

Figure 2: Integrating optiSLang into the calibrating process

2 Simulation method

The FE program PAM-STAMP 2G (ESI group) is used for simulative mapping of the joining process. As the schematic example of a spot welded joint shows in Figure 3, modeling the joining process can be broken down into the simulation steps below:

1. positioning and clamping the specific components.
2. connecting the joining components with rigid girder elements at the position of the electrodes
3. using mapping to implement substitute mechanical loads in the form of tensions (stress) in the area of the joining point, and
4. calculating the balance from which a change in the geometry results on the component part.

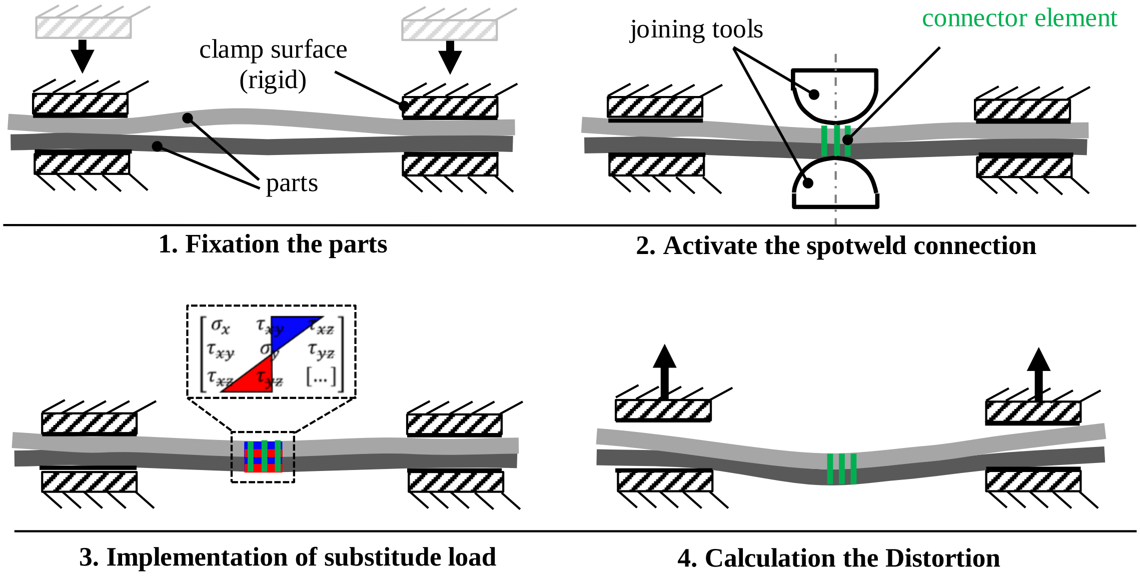

Figure 3: Simulation steps to compute the joining process

3 Parameter identification

3.1 Input parameters

2-D shell elements are used to make the assemblies to be joined in the FE model discrete in conformity with Belytschko-Tsay element formulation. These shell elements are mostly used in the sheet metal forming simulation and describing the behavior up to 5 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 described in Figure 3 (ref. with Step 3) to reach the distortion measured in Point 2 in Figure 1. This consciously enables the user to control the intensity of distortion of 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 that the simulation model comes closest to the experimental reference during the calibration processes.

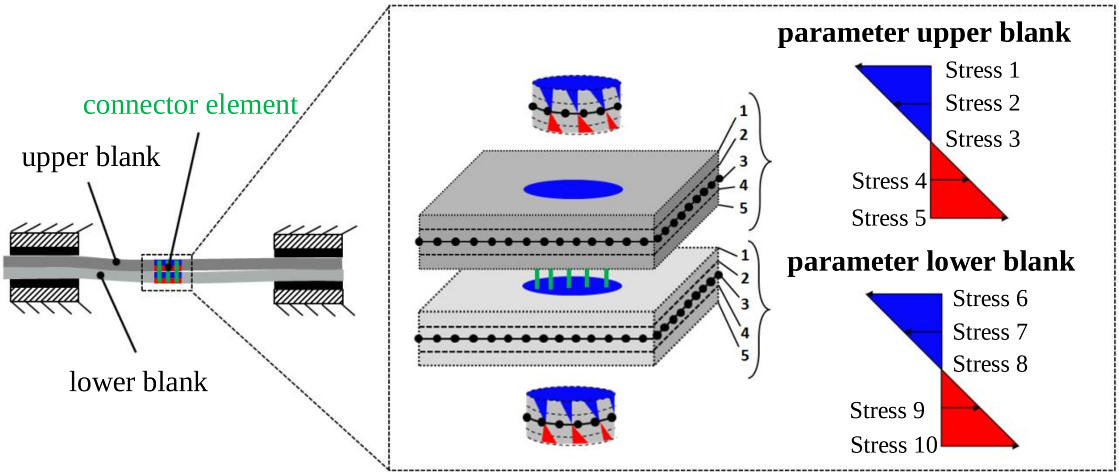

Figure 4: Identifying the parameters on the 2-D shell element

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 fact that both the upper and lower blanks are supposed to be mapped with substitute mechanical loads independently produces a total of ten input parameters for optimization (see Table 1). The input quantities derived that are supposed to describe the behavior of the shell cross-section mathematically are shown in Figure 4. Furthermore, the parametrized stress from the optimization algorithm can be continuously varied for the upper and lower blank to search for the optimum design configuration where the pressure and tensile stresses can assigned to the shell elements in the joining zone.

3.2 Objective criterion

Discrete measuring points are defined as targets on the entire surface of the assembly of the calibrating model that give the space in the Z-direction of the simulation model (ACTUAL) to the experimental reference (TARGET) at the end of a simulation run-through. Figure 5 shows the definition of the targets on the calibration model.

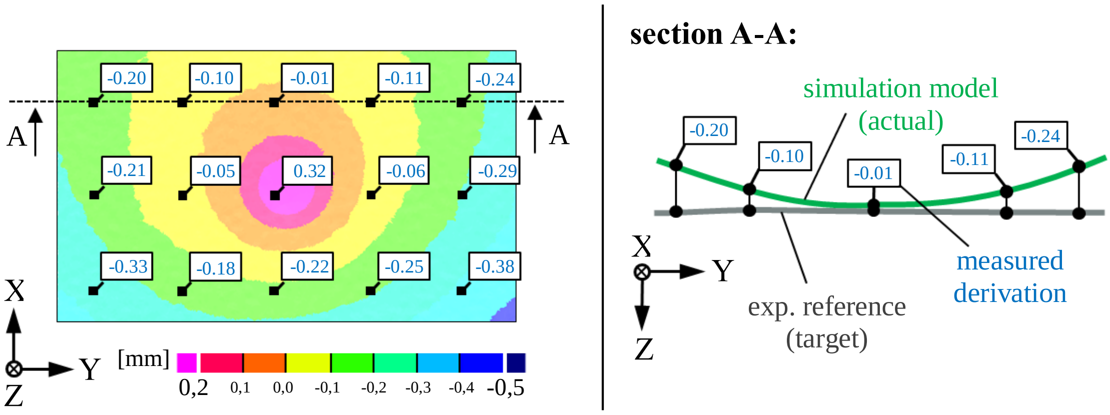

Figure 5: Objective definition

To be able to take in the entirety of the measuring points, it is necessary to use a target function to combine the effective interrelationships discovered into an optimization model. The value of the target function is calculated from the total of the squared spaces between the experiment and simulation at the specific measuring points. The objective of optimization is minimizing this function value; in other words, minimizing the amount that the simulation model and experimental reference differ from one another at all measuring points.

4 Case study

A real-life example of car body engineering will be used for examining the functionality of the calibration procedure 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 (ref. with Figure 6). Specimen no. 1 will be used to automatically calibrate the model with optiSLang. In turn, specimen no. 2 will be used to check the quality of calibrated substitute model for the second situation. Finally, any divergences between the experiment and simulation will be calculated.

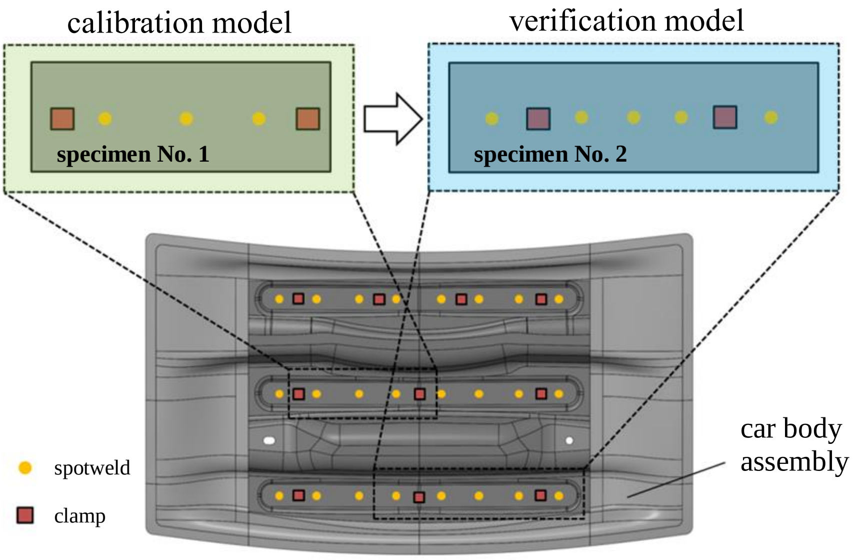

Figure 6: Test specimens used during the test

4.1 Calibration model: specimen no.1

Because the number of parameter to be calibrated is with 10 still small the optimization 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 gets a value smaller than 0,01. The convergence procedure of the ARSM can be seen from the objective history diagram in Figure 7 (left) and the parameter history diagram for the parameter Unterblech_Stress5 in Figure 7 (right). In this connection the optimizer reliably converges after a total of nine iterations (90 simulations) and reduces the functional value of the target function of 1.2 in the first iteration loop to the user defined stop criterion of approximately 0.033 in the final iteration step. Finally, optimizing the substitute loads requires approximately three hours with four simulations in parallel. That means that it is possible to reach the target of reducing the simulation time for the calibration process to less than 4 hours without any problems.

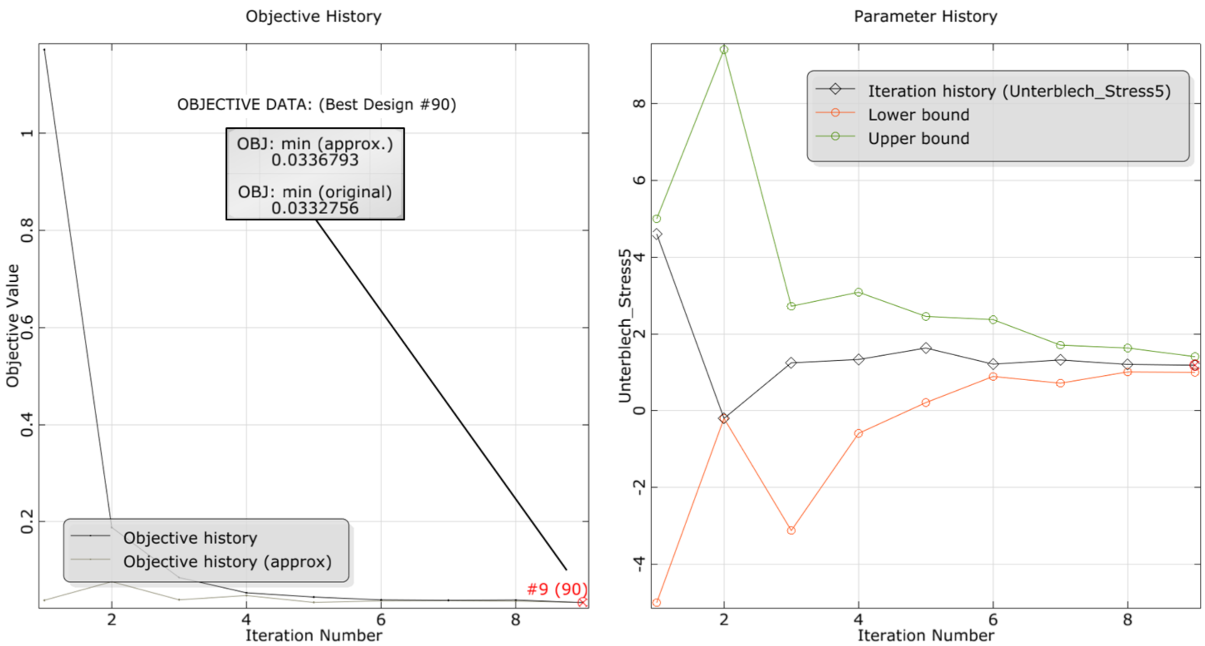

Figure 7: The objective history diagram of the ARSM algorithm (left) and the parameter history diagram of the Parameter Unterblech_Stress5 (right)

The resulting deformation from both the experimental reference (blue) and the simulation (red) are referenced to the design state (CAD-0) to evaluate the quality of calibrating. The welding distortion is evaluated along the cutting plane designated on the upper and lower blank in the sheet normal direction (ref. with Fig. 8).

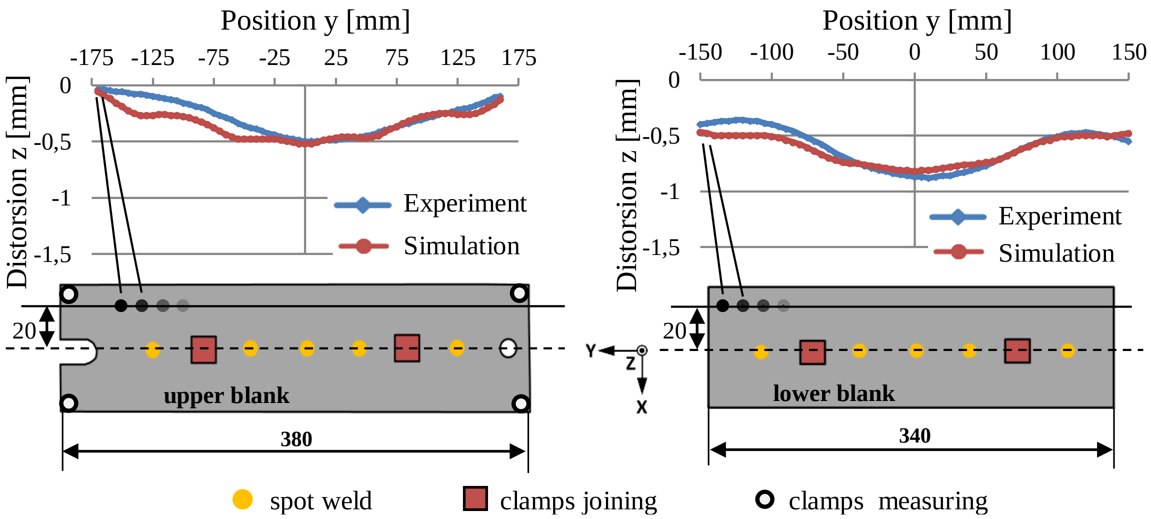

Figure 8: Calibration results (Simulation vs. Experiment) for specimen no. 1

The deviations predicted in the simulation show excellent agreement with the experimental data and the maximum difference of the distortion values from the simulation and experiment are less than 0.07mm on both the upper and lower blank. In sum, it can be concluded from the calibration of specimen no. 1 that the ARSM algorithm finds the matching configuration within a few iterations so that the time and effort for identifying suitable substitute loads can be substantially reduced. The calibrating quality achieved is high in this example which makes it the prerequisite for achieving a high quality of results when transferring substitute mechanical loads to more complex applications.

4.2 Verification model: specimen no.2

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

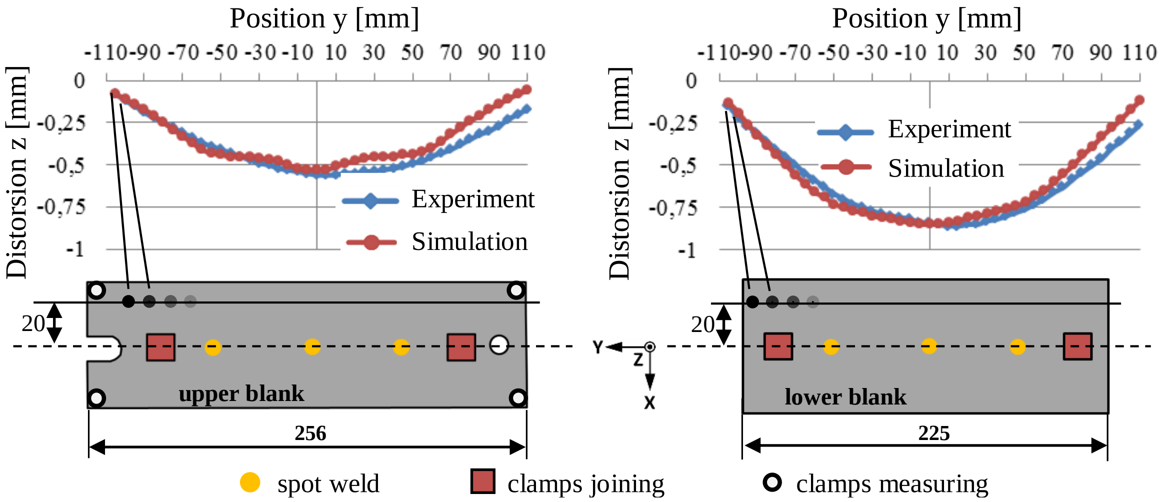

Figure 9: Comparison of measured and simulated distortions of specimen No. 2 (Calibration model: specimen No. 1)

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 that the high level of calibrating quality of specimen no.1 makes the substitute mechanical model capable of predicting reasonable distortions when it is transferred to more complex applications.

5 Conclusion

To date, substitute mechanical models were exclusively calibrated in an experienced-based analytical process. So the substitute mechanical loads needed for matching the distortion had to be calibrated by hand and based upon experience until the joining distortion from the experiment and simulation agreed. This not only called for a high level of user expertise, but especially time-consuming change loops. Therefore, this article demonstrated the potential of optimization-based model calibration. The optimization algorithm used reduced the time and effort for calibrating the substitute parameter to a couple of hours while maintaining a high level of calibrating quality.

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