Industrial application of welding temperature field and distortion visualization using FEA†

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1. Introduction

The non-uniform heat input during the welding process leads to problematic permanent deformations of welded parts. The control of these welding distortions is, with the absence of the knowledge of the fundamental mechanisms responsible for these deformations, an extremely time and cost consuming iterative “trial-and-error” optimization process. The visualization of the involved physical phenomena, like temperature and distortions, is an indispensable tool to clearly identify these mechanisms in order to adapt the welding parameters and clamping conditions target-oriented. Both experimental and virtual methods exist to obtain these physical data, however the possibilities to visualize them with experimental methods are laborious, expensive and limited in their application. Welding simulation using finite element analysis (FEA) offers many benefits and has a great potential to reduce the experimental effort. Nevertheless, the industrial application of welding simulation is not yet established widely because of reservations regarding the computation costs and the resulting accuracy for instance.

In this paper, the results of a case study for a welding simulation with an industrial background are presented. A welded assembly from the automotive industry has been investigated with numerical and experimental methods. A comparison between both methods demonstrates the potentials of welding simulation in terms of visualization. Furthermore, the numerical results reveal the possibilities of current resources regarding calculation time and result accuracy of an industrial applied welding simulation.

2. Welded assembly and experimental set-up

The welded assembly investigated in this work belongs

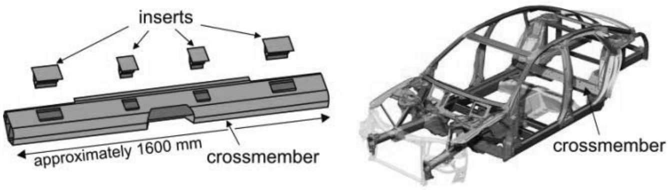

Fig. 1 Investigated assembly and its position in the A8 AUDI-Space-Frame (ASF®).

to the AUDI-Space-Frame (ASF®) (**Fig. 1**) of the predecessor of the current AUDI A8 and consists of a crossmember (1600 mm x 180 mm x 80 mm) and four inserts all made of AlMgSi alloy. Two MIG welds were applied per insert, giving a total of eight welds. The entire weld seam length is approximately 500 mm.

For the case study, measurements of transient temperature cycles and distortion fields have been done. The temperature cycles have been obtained with thermocouples and the transient 3D distortion field has been measured with an optical 3D analysis system, ARAMIS. The evaluable measurement field of this optical analysis was restricted by the experimental set-up like clamping devices, robot arm and limitations of the measurement equipment to a quarter of the assembly.

The execution of the experiments with the measurement equipment, e.g. CCD cameras and spot lights, is not possible in a real production line. Hence, the experiments were executed at the Federal Institute for Materials Research and Testing (BAM), Berlin. For this purpose a clamping fixture equivalent to the real clamping device was designed. A more detailed description about the experimental set-up is given in [1].

3. Numerical set-up

The simulation results presented in this paper have been done with the commercial welding simulation software SYSWELD™ 2009 on a fast desktop PC (Intel Core i7 950@3 GHz and 12 GB RAM) with a Linux operating system. The mechanical calculation time for the investigated 150.000 nodes large FE-model is approximately 15 h, so the simulations can be done overnight, which is a reasonable time frame.

Assumptions and simplifications according to the current state of the art were assumed to run the simulations. A key assumption is the reduction of the complex real physical welding phenomena to a phenomenological heat source model. The parameters of this heat source have to be calibrated iteratively by an adjustment of the numerical calculated temperature field to match the measurements of the thermocouples and cross sections. In this study, a moving volumetric heat source with a double ellipsoidal distribution

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proposed by Goldak [2] has been used to describe the MIG-welding process. After calibration of this phenomenological heat source, the simulated temperature distribution is in best agreement with experimental data.

The necessary temperature dependent material properties of an AlMgSi alloy were taken from [3]. Softening effects occurring in the heat affect zone of a T6 tempered aluminum alloy are taken into account using the microstructure model developed by Leblond [4]. The parameters of this model were calibrated against hardness measurements across a weld seam of the actual alloy.

The calibrated temperature distribution is used as an input for the subsequent mechanical calculation, which determines the distortions according to the calculated temperatures. The mechanical boundary conditions were applied to the experiments equivalent places and removed at equivalent times. Orthotropic elastic constraints were used to reproduce the clamping conditions. It should be noted that, in contrast to the production, in this study the assembly was not fully unclamped. One side of the crossmember was clamped over the entire measurement period to suppress rigid body motions and thus enable the direct comparison of experimental and numerical results at defined reference points.

4. Results and discussion

The calculated distortions according to the calibrated temperature field are shown in **Fig. 2** as a contour plot of the entire assembly with a magnification factor of 25. In addition to the shown distortions many further physical data can be visualized flexible at the surface or in the inside of the investigated part for each recorded time step by a calibrated welding simulation without any problems or restrictions.

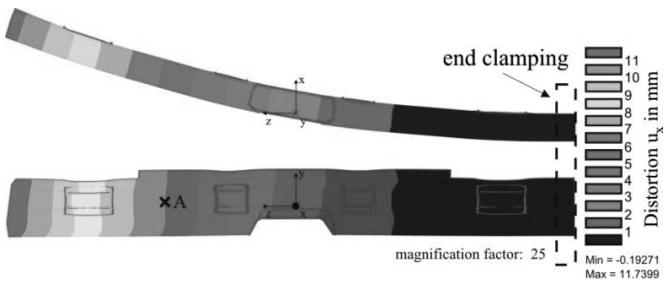

Fig. 2 Simulated distortion distribution (magnification factor: 25).

In contrast to that, the experimental visualization of many of these physical data is very complex, restricted or even impossible. Clamping devices, welding robots and the welding process itself limit an observation during the welding process to small sections. An experimental visualization of the entire assembly is usually possible only for unclamped conditions before and after the joining process.

Furthermore, the numerical approach offers, in contrast to experiments, the opportunity to examine the influences of individual parameters by an uncoupled parameter variation, so that the fundamental mechanisms responsible for the deformations of welded parts can be clearly identified. The welding simulation therefore offers significant benefits in terms of visualization in comparison to experimental methods. Nevertheless, an advantage of the experimental observation is the direct measurement of the real component behavior. The result quality of a welding simulation, however, is highly dependent on the accuracy of the calibrated temperature field and the chosen assumptions and simplifications.

The result accuracy of this study is illustrated in **Fig. 3** as a comparison of the numerical and experimental transient distortion behavior at point A. Qualitatively, the characteristics of the welding distortions are well reproduced by the simulation. Quantitatively, the calculated distortion is approximately 60 % higher than the measured one. Considering the simplifications and assumptions of the simulation model the result accuracy is reasonable.

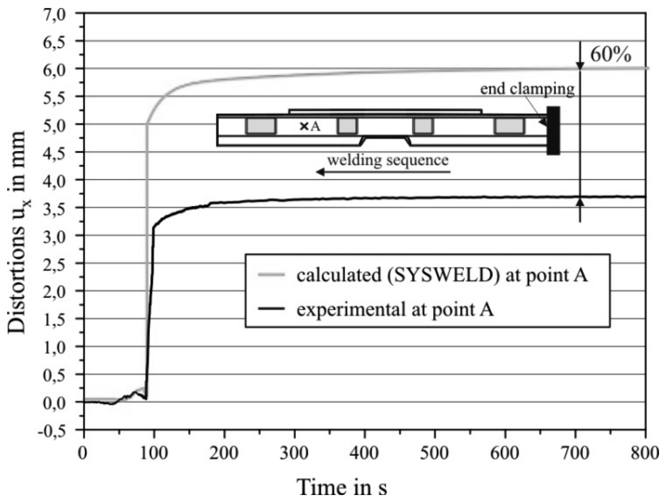

Fig. 3 Comparison of calculated and measured transient distortions at Point A.

5. Conclusions

As shown in the previous section the increasing computational power enables us to run a 3D nonlinear transient welding simulation for a large industrial geometry in a time frame that allows a widely industrial application of welding simulation. In this case, the calculation could be done overnight on a desktop PC.

Finally the results of this study show that the calculation of complex and large industrial parts with good result accuracy and a reasonable calculation time is possible. Welding simulation, therefore, has a great potential with its strengths in visualization and the specific examination of parameter influences to reduce experimental effort within a target-oriented distortion optimization in industrial environments. However, additional research is needed with respect to the time-to-solution (e.g. automatic heat source adjustment and meshing) and the user-friendliness of the software in order to become even better suited to industrial requirements.

The conclusions of this study are summarized as follows.

(1) A welded assembly from the automotive industry has been investigated with experimental and numerical

methods.

(2) The results of the simulations show that current resources allow an industrial applied welding simulation with good result accuracy and reasonable calculation times.

(3) Compared to experimental methods the flexibility of welding simulation offers great advantages in terms of visualization. Many physical data can be visualized without any problems and restrictions.

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