Determination of weld joint strength by welding simulation

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Abstract

During welding, the material properties change in the weld pool and in the heat affected zone. Likewise, previous heat treatments are affected by welding. This is due to the thermal load during the welding process. The strength and the failure behaviour are needed for further analysis like crash or ultimate load evaluations. State of the art is the determination of weld strength by tension tests of the welding zone.

The future goal is to replace physical tests with numerical analyses. This paper discusses a laser welded overlap joint of thin sheet made of 22MnB5. The sheet is heat treated by press hardening thus annealing occurs in the heat affected zone which leads to softening. The hardness and the microstructure are calculated by welding simulation. The results are used to generate crash cards related to material state. These crash cards, which incorporate the GISSMO model, are applied on the mechanical model to simulate the load-displacement behaviour of the connection until rupture.

1   Introduktion

For the prediction of the load capacity of a welded joint, it is necessary to know the structure of the weld. In recent decades, the welding simulation has developed and offers the possibility to determine the required material properties after welding [Goldak, 2005]. Particularly, the welding structure simulation is a calculation method that can be used to calculate distortions, mechanical stresses and strains, as well as structural states and microstructural transformations in thermally joined components [Loose, 2007].

The material models for the welding structure simulation include several phases, but no descriptions of the damage. In the welding simulation, the processes associated with phase transformations can thus be taken into account: heating, cooling and reheating in multi-layer welds, including tempering.

For crash simulations, in which limit load capacities are also determined, these models cannot yet be used, because failure models are not integrated.

In general, it is assumed in the crash simulation that the mechanical properties of the material for calculating the breaking strength are in the state of delivery of the material. The property changes [Gurney, 2006] resulting from the previous treatment in the process chain are ignored. One model that can integrate the stress state of a previous forming simulation is the GISSMO model [Neukamm, 2009].

In order to be able to consider the history of the material (elongation history from the welding process), the required material data are therefore determined based on complex multi-axis tensile tests.

In general, during welding, in addition to the melting of the material, a heat treatment of the solid material in the heat-affected zone (HAZ) takes place, which leads to the tempering of the material and to the change in the mechanical properties in this area. This tempering is particularly pronounced in multi-layer welds. Not only the base material but also the existing welding layers are tempered. Thus, there is a multi-phase heterogeneous material structure in the region of the weld,

which has a significant influence on the load-bearing behaviour or the fracture behaviour of a connection and is not yet comprehensively integrated in today's state of the art in the numerical welding structure and crash simulation. Particularly in the case of low-alloyed, high-strength, multiphase steels, the forming of the microstructure and the changes in the material properties have not yet been implemented.

2 Welding Simulation

Based on the example of a laser welded overlap joint of thin sheets made of 22MnB5, the welding structure simulation was carried out in a first step. The simulations were performed with the preprocessor DynaWeld, which is specially adapted to the requirements of the welding structure and heat treatment simulation and the solver LS-DYNA. All experimental investigations as well as the material cards used within the damage simulation are part of the research project: "UHSS WEZ Kennwertgenerierung" of the Forschungsvereinigung Stahlanwendung e.V. (FOSTA) (P1232/18/2017). Temperature dependent material properties of 22MnB5 were calculated via the materials simulation tool JMatPro. The computational mesh was refined in the areas of the molten bath and the HAZ. The edge length of the elements in the molten bath is about 0.3 mm and in the HAZ about 0.4 mm. In Figure 1, a clipping of the mesh is shown.
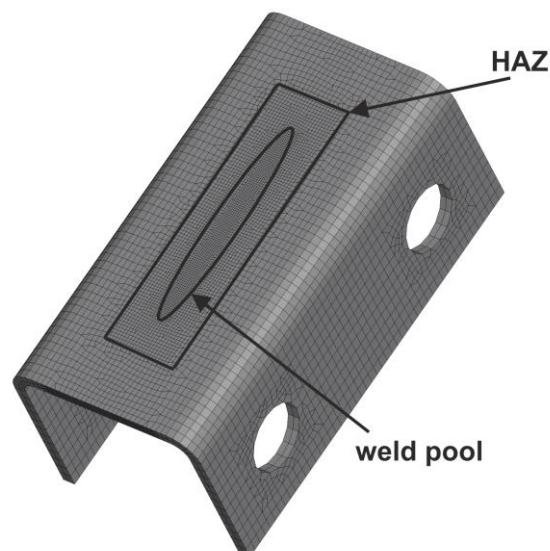

Figure 1: mesh refinement at the weld pool and the HAZ

The heat source used for the laser welding process was a double-conical heat source with constant heat source density developed by DynaWeld. In Figure 2, the comparison between the simulated heat input and the experiment is shown.
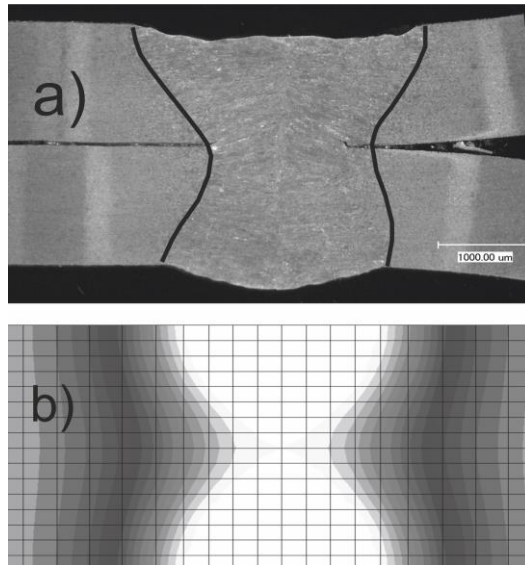
Figure 2: Weld pool a) experiment b) simulation

To calculate the hardness, a material-specific hardness formula was generated based on [Aker-ström, 2006]. This formula also considers the formation of tempered martensite and a segregation zone at the border of the melt pool. The phase transformation from martensite to tempered martensite was calibrated according to a linear mixing rule with respect to yield strength and tensile strength.

Figure 3 shows a comparison between the calculated and the measured hardness profile in the welding zone and the HAZ. The maxima of this profile are caused due to the segregation effect at the border of the weld pool. The weld pool consists of a martensitic plateau with a constant hardness of the base material.
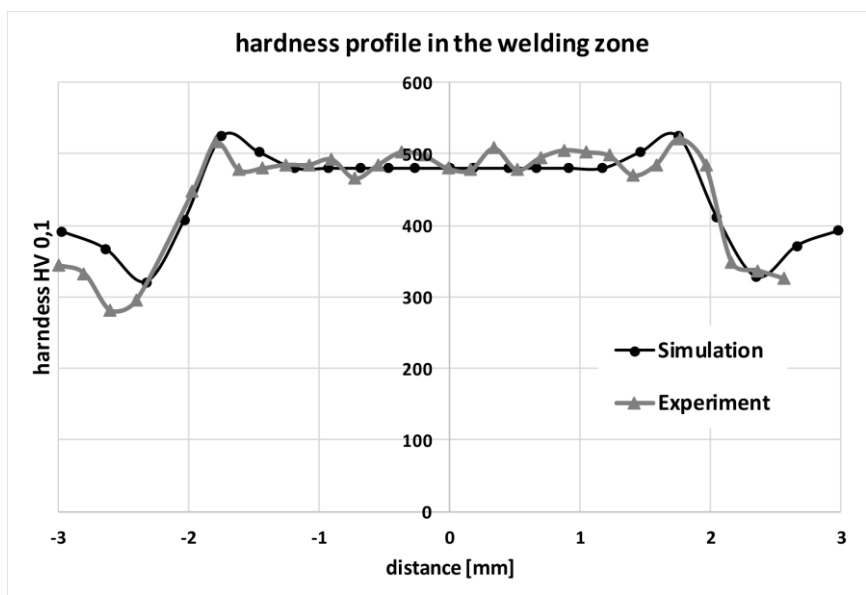

Figure 3: calculated and measured hardness in the welding zone

The segregation zone, which reflects the fringing edge of the melt pool, was modelled by a specific temperature interval. The shape of this zone is shown in Figure 4.
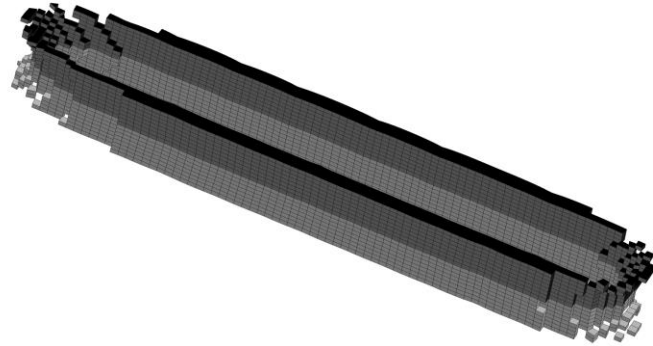

Figure 4: shape of the segregation zone

3   Part creation according to material properties

In order to transfer the different material properties in the HAZ to the failure modelling, different material cards must be created. For this purpose, it is necessary to divide the base material into different parts. In DynaWeld a module is integrated, which automates this process. The input variables are the field variable to be subdivided, the number of subdivisions and their limitations. As an output you get a subdivided multiple part component and it is now possible to assign a different material card to each part.

In this example, the hardness distribution was used as the main criterion for differentiating the material properties for the failure modelling. Thus, the hardness profile was divided into 5 zones. This partitioning procedure has no influence on the mesh. All existing elements are assigned to the respective parts. Figure 5 shows the continuous hardness distribution and the newly created parts generated with this method.
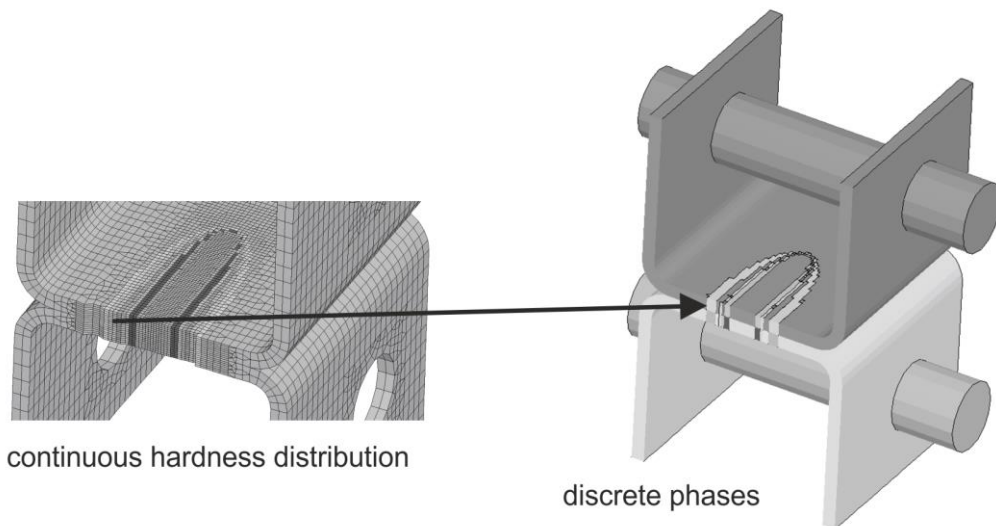

continuous hardness distribution

discrete phases

Figure 5:   Transfer of the continuous hardness distribution into discrete parts

4   Damage simulation

The parts generated with this method have been assigned the appropriate hardening curves and failure curves, so that the GISSMO damage model is applicable. Afterwards an explicit cross tension test was simulated with LS-DYNA. Figure 6 demonstrates the failure in the weld seam.
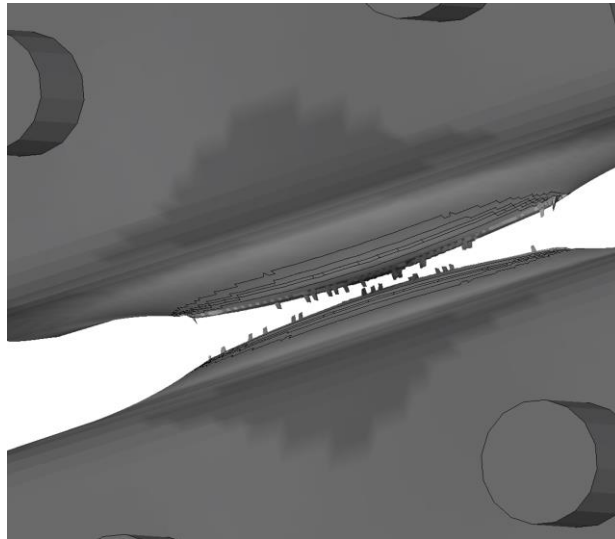

Figure 6:   Failure in simulated cross tension test

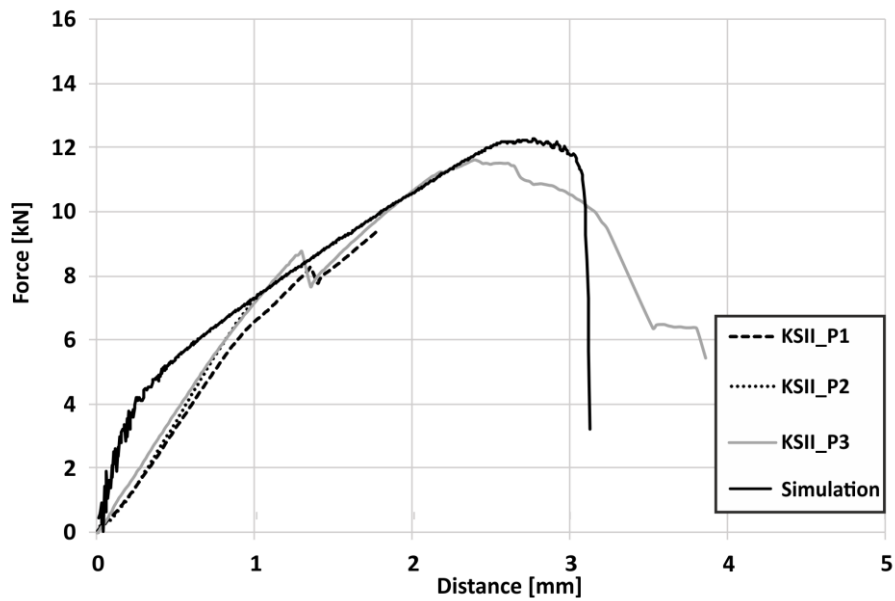In figure 7, a comparison between the simulated force-distance diagram and the experiment is shown.

Figure 7:   Comparison between simulated force-distance diagram and experiment

5 Conclusion

Using the example of the press-hardened 22MnB5, the process chain: welding simulation, failure simulation could be successfully carried out. An assignment of the microstructural states occurring in the HAZ to discrete material cards took place after the welding process. For this purpose, a tool integrated in DynaWeld for the automated partitioning of the basic geometry was used. In further investigations the transferability to further materials is examined.

6 Literature

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