FEM ANALYSIS OF DEBONDING PROBLEMS DURING BI-METALL WIRE JOINING OF ALUMINUM AND STEEL SHEETS

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Abstract

Zinc-coated steel sheets have been joined with aluminum samples in an overlapping as well as in a butt-joint configuration. A bi-metal-wire composed from aluminum and steel was used as a filling metal in a series of welding experiment. An advantage of the laser-assisted bi-metal-wire welding is that the welding process is simplified since the primary joint between aluminium and steel exists already and laser welding occurs only between similar materials. FEM-simulations of the process were chosen to determine the proper dimensions with respect to the formability and thus possible debonding of the bi-metal-wire.

Key words

laser welding;bimetal, FEM, debonding

Introduction

During the last years, the amount of steel used in manufacturing has decreased continuously. As a consequence, plastics and light metals have replaced many parts previously manufactured from steel.

Many different joining methods, like riveting, bonding and many others are in use to join such components of unequal composition. Due to its excellent properties, aluminum is one of most-used light metals in car body manufacturing.

Unfortunately, laser assisted joining of aluminum and steel tends to the formation of brittle intermetallic phases. Nevertheless, laser joining methods have been examined during the last years at many different laser centres world-wide. It has been shown that laser joining of aluminum-steel components is possible if process parameters are chosen carefully [1-4].

Bi-metal-wire laser welding

All bi-metal-wire welding experiments have been performed in a butt-joint configuration. Within a first step, the wire was welded to one material and in a second step the remaining interface has been welded. In any case, laser welding occurred only between similar materials (aluminum-aluminum and steel-steel). At the beginning the influence of subsequent laser welding on the primary joint of bi-metal-wires has been analyzed. FE-simulations indicate that the primary joint between steel and aluminum remains unchanged if minimal wire dimensions are not under-run.

Additional simulations should help to evaluate the possibility of using a conventional wire-feeder to deliver the bi-metal-wire to the welding zone.

Coupled field thermal-stress analysis

In the frame of the theoretical modelling the series of different simulation models were developed. Some of them should be considered well known and oft described. This paper represents the contribution to the analysis of thermally induced deformation computed by the ANSYS software.

The 3D model for thermal-stress analysis was initially developed to simulate at first the internal stresses induced by pure heat input. The obtained results (***Fig. 1***) indicate the main problems due to significant difference between material properties of Al and steel, especially thermal linear expansion and thermal conductivity. High heating rates generate high deformations of aluminum leading to the high stress at aluminum-steel interface (red arrows). This was indicated as the possible source of the debonding problems.

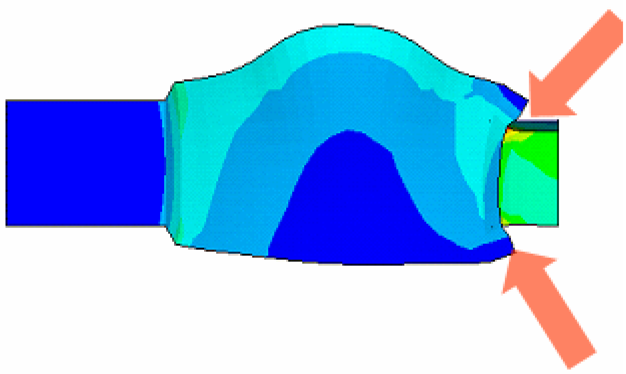

Fig. 1 *Thermally induced deformation and von Mises stresses, deformation scale factor 50x, red arrows indicates the possible source of initial debonding (laser power 2 kW, absorption 12 %, welding velocity of 1.2 m/min; load steps 50; time step 44.31 ms)*

Debonding model

The specific nature of the bi-metal-wire, namely some debonding problems on the aluminium-steel interface required another simulation approach, the simulation of interface delamination within the ANSYS software environment.

Interface delamination with contact elements is referred to as debonding. Debonding in ANSYS is modelled with contact elements which are bonded and have a cohesive zone material model defined. Our debonding model was developed to evaluate the possibility of the use of conventional wire-feeder to deliver the bi-metal-wire to the welding zone.

ANSYS provides two cohesive zone material models with bilinear behavior to represent debonding. The material behavior defined in terms of contact stresses (normal and tangential) and contact separation distances (normal gap and tangential sliding) is characterized by linear elastic loading followed by linear softening. Debonding allows three modes of separation:

- Mode I debonding for normal separation
- Mode II debonding for tangential separation
- Mixed mode debonding for normal and tangential separation.

Debonding is also characterized by convergence difficulties during material softening. Artificial damping is provided to overcome these problems. An option for tangential slip under compressive normal contact stress for mode II and mixed mode debonding is also provided.

The cohesive zone material model with bilinear behavior is defined as [5]

$$P = K_n u_n (1 - d) \tag{1}$$

$$\tau_y = K_t u_y (1 - d) \tag{2}$$

$$\tau_z = K_t u_z (1 - d) \tag{3}$$

where

P	normal contact stress (tension)
τ_y	tangential contact stress in y direction
τ_z	tangential contact stress in z direction
K_n	normal contact stiffness
K_t	tangential contact stiffness
u_n	contact gap
u_y	contact slip distance in y direction
u_z	contact slip distance in z direction
d	debonding parameter.

Based on the previous experience, two different delaminating models were developed: 2D model with the cohesive element interface definition and 3D model with contact elements (***Fig. 2***, ***Fig. 3***) presented below.

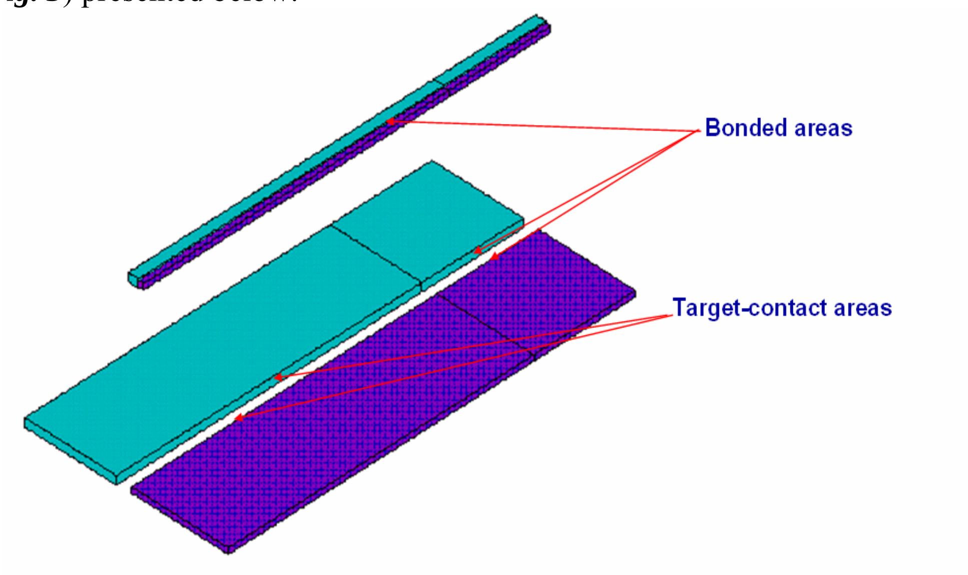

Fig. 2 *3D model with contact cohesive elements – contact and bonded area*

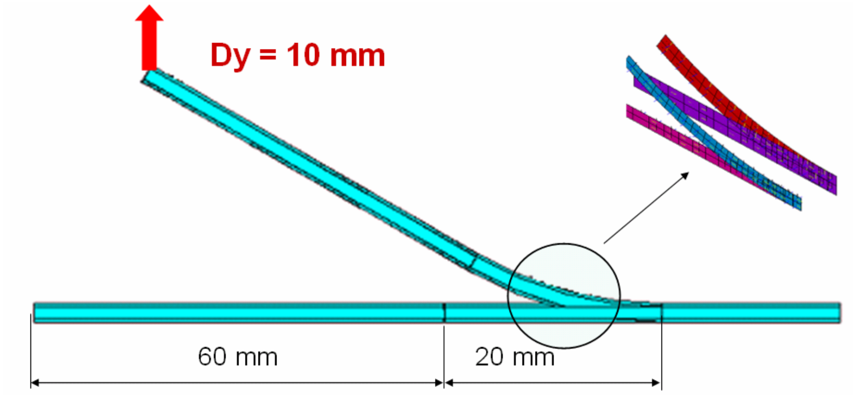

Fig. 3 *3D model with contact cohesive elements, dimensions and load*

The geometry of the model was focused on the prediction of conventional wire-feeder usage to deliver the bi-metal-wire to the welding zone. 3D model presented in the paper provides the detailed information not only about the stresses and the model deformed shape (***Fig. 4***) but also about the contact status itself.

Fig. 5 illustrates the zoomed view on the bonded contact area (deformation multiplication factor 5x). This figure clearly shows that approximately 2/3 of the originally bonded (welded) connection is already damaged. In the ***Fig. 6***, tangential stresses due the contact are shown. In ***Fig. 7***, the deformed shape (multiplication factor 20x) and maximal model stresses are depicted. Begin of the welded connection is shown as the edge.

This behaviour of the bimetal – steel and bimetal Al-alloy connection definitely exclude any bimetal wire feeding with the classical wire feeder.

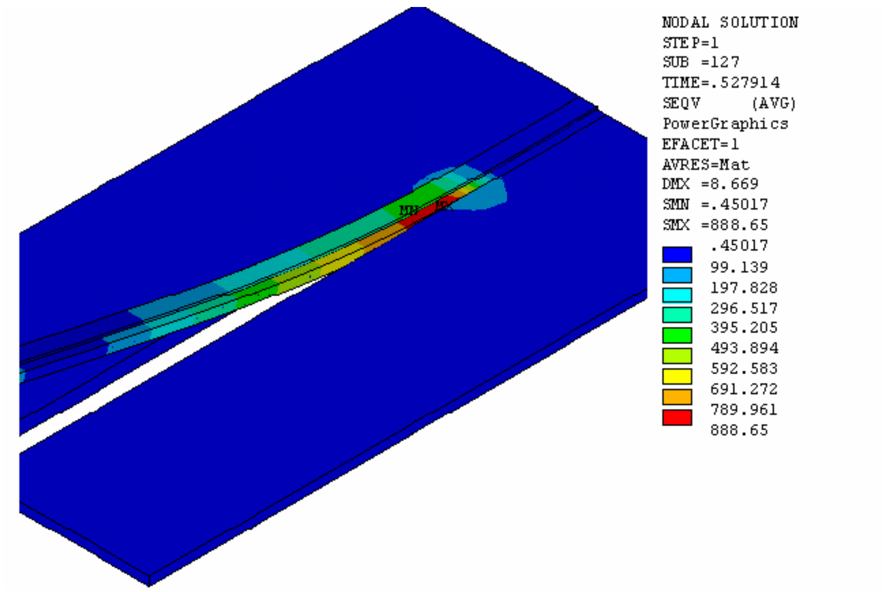

Fig. 4 *3D model – von Mises stresses after 10 mm bimetal wire free end displacement*

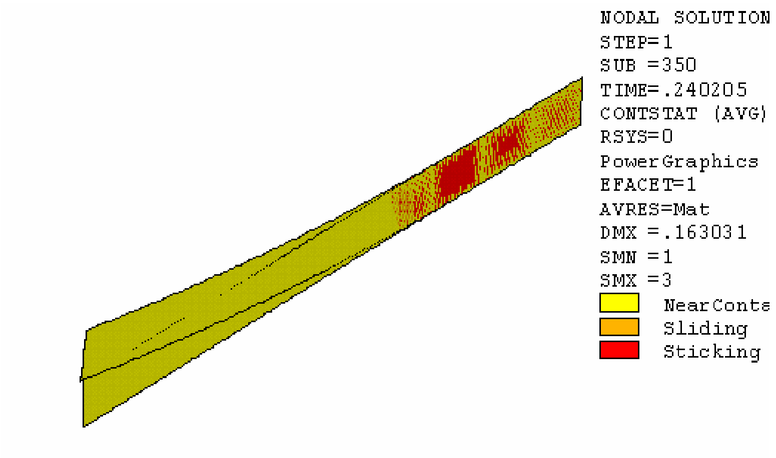

Fig. 5 *3D model – contact status after 10 mm bimetal wire free end displacement*

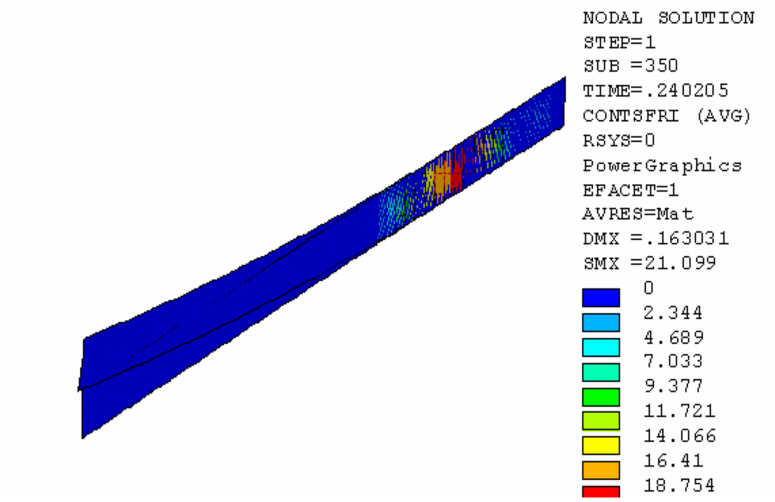

Fig. 6 *3D model – contact stresses status after 10 mm bimetal wire free end displacement*

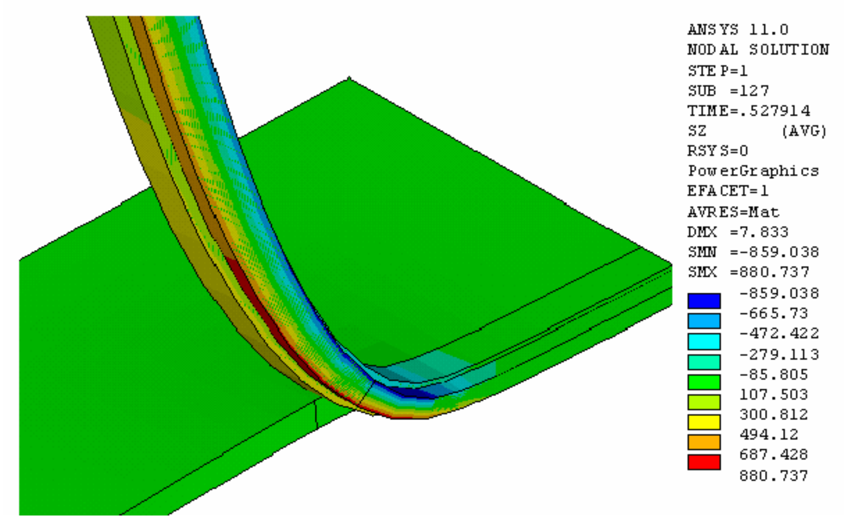

Fig. 7 *3D model – von Mises stresses after 10 mm bimetal wire free end displacement, deformation scale factor 50x*

Conclusion

In the paper, the coupled field FEM-simulations models focused on the simulation of thermal load in coalescence with bending and torsion momentum is presented. The models have been used for determination of the proper dimensions with respect to the formability of the bi-metal-wire. Coupled field FE analysis of the formability at welding temperatures exhibited the processing limits of bi-metal-wire welding. First experiments exposed that no modification of the primary joints between aluminum and steel appeared by subsequent laser welding. Results of tensile tests indicated that samples failed in the vicinity of the primary joint at the aluminum part of the bi-metal-wire. Nevertheless, prototypes developed later shows the feasibility of the process.

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