Modelling of the deformation and fracture behaviour of laser welds for crash simulation

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Summary:

The light weight potential in automobile fabrication is increasing due to the development of new high strength steels. The realisation of this potential requires the use of adjusted joining techniques for the combination of optimized material properties with optimized joint properties. With the development of laser welding to a series-production technology a joining technique is available to practise the light weight potential of high strength steels. The advantages of laser welding compared to conventional welding techniques are the high process velocity, the low thermal influences of the material and the flexibility in joint figure and position [1, 2]. The flange width can be reduced that leads to weight reduction and design advantages. Softening in the heat affected zones beside the welds is avoided because of the compressed heat input during laser welding. The strength of the high strength steels remains in the joint.

The application of laser welding is increasing for joining automotive components to the body in white [3]. But laser welding is less used compared to conventional joining techniques like spot welding. The reasons are the missing knowledge about crash worthiness of laser welds and missing methods to model the laser welds in crash simulation. The questions are how laser welds behave under crash loading: What are the experimental methods for a reliable characterisation? What are the numerical methods for an efficient simulation of the load-bearing capacity of the joints? A working group of FAT AK27UA crash and occupants simulation initiated a research project to answer these questions.

Two different weld geometries of laser welded step welds were investigated. Those are short linear and c-shaped welds as single parts of the step welds. The investigations of the laser welded joints are done using two different steel kinds. First a low strength steel, DC04, with a tensile strength of about 300 MPa and second a high strength steel, TRIP700, with a tensile strength of about 670 MPa are used. The laser welding of the 1.5 mm and 2.0 mm thick steel sheets was done by Daimler Forschung in Ulm, Germany. Metallographic investigations of the welds were done. The welds were cutted and grinded and hardness profiles were measured over the weld. The average hardness was about 200 HV0.1 in the weld metal of DC04 linear welds compared to 100 HV0.1 in the base metal. The average hardness was about 470 HV0.1 in the weld metal of TRIP700 linear welds compared to 215 HV0.1 in the base metal. The width of the linear laser weld was about 1 mm and the length of the single linear laser weld was about 18 mm.

Single welds were characterised using different specimen geometries to realise different loading situations like shear, tension, bending and combined shear-tension (KSII-0°,-30°,-60°,-90°, coach-peel and shear-tension specimens). For investigation of strain rate effects the loading velocity has been varied between quasi-static and 1.5 m/s. The load bearing capacity of the DC04 linear laser weld under shear-tension and KSII-0° are less (about 10 %) than under tension (KSII-90°) loading. The linear laser weld is shear loaded in weld direction with the KSII-0° specimen and perpendicular to the weld direction with the shear-tension specimen. In both shear loading cases the weld fails through interfacial fracture. In all other loading situations like KSII-90°,-30°,-60° and coach-peel the welds were

buttoned out or peeled out of the connection. While investigating the linear welds in TRIP700 some changes in fracture mode occurred. Here, interfacial fracture occurred also in other loading situation especially under bending loading in the coach-peel specimen test. The scattering of load bearing capacity is higher as a result of the changes in fracture mode compared with the results in DC04 steel.

For investigation of the local loading situation a detailed model with solid elements for the sheets and the weld is used containing different material zones for base metal, heat affected zone and weld metal. The result of this detailed simulations was, that the loading in the weld line is not homogeneous. For example under tension loading, KSII-90°, there are high normal stresses located in the base metal at the ends of the linear weld. The distribution of loading is also seen in a simplified model. Here the laser weld of 18 mm length is modelled using five connected solid elements. The metal sheets are modelled with shell elements, of course. The elastic-plastic material model *MAT_024 without failure strain is used for the shells. The cohesive material model *MAT_ARUP_ ADHESIVE is used for the solid elements of the laser weld defined here as cohesive elements. The fracture parameters of *MAT_ARUP_ADHESIVE are determined with simulation of shear-tension and KSII-90° tests taking into account the local distribution of shear and normal stresses in the weld. The exponent in the fracture law is optimised using the test results of KSII-30° and -60°. It is possible to model the coach-peel and KSII-0° tests, which were not used for parameter determination. But this is only possible for the laser welds in DC04. The same strategy leads to an overestimation of strength of nearly 100 % in the coach-peel simulation for TRIP700 laser welds because of the changes in fracture mode. To take this into account, a separate fracture criteria for bending is necessary and a material model for spot welds, *MAT_SPOTWELD_DAIMLERCHRYSLER, was used successfully taking energy absorption behaviour with the new option DG_TYP=3 into account.

For the verification of the laser weld modelling component test are done using a so called T-specimen with four or six critical loaded laser welds depending on the loading direction. The simulations of the component tests with specimens made of DC04 have shown a good agreement with the test results using the cohesive material model for the simplified laser weld model. While simulating the TRIP700 component tests with the spot weld model the basic necessity of modelling the energy absorption was shown.

Keywords:

laser welding, characterisation of joints, testing of joints, simulation and simplified modelling of laser welds, crash simulation, component tests and simulation

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