Dissertation title:

Process strategies to avoid hot cracking mechanisms during remote laser welding AlMgSi 6016

Peter Stritt

Continuously rising material prices and strict emissions legislation are increasingly resulting in the use of lighter materials in the automotive industry. Aluminium is therefore one of the most relevant materials used to realise lightweight construction. From the production point of view the necessity of appropriate joining technologies exists. In terms of aluminium, laser welding is a well-established joining technology.
However, hot cracking is one of the major issues in laser welding of high-strength aluminium alloys. Additional filler wire can be added to the fusion zone within the welding process in order to prevent hot cracks. But the use of such wires is not desirable since it proved to be cost and time consuming and is not compatible with the highly requested remote laser welding process.
As an alternative to the use of filler wire, several other approaches to overcome the hot cracking issue are discussed in literature. Some of these approaches are considered within this thesis and categorized into the three main methods using a metallurgical, thermal or mechanical approach to prevent hot cracking.
A theoretical analysis based on a finite element model is performed in order to obtain a better scientific understanding of the hot cracking mechanisms during laser welding in close-edge position. High speed videos from experimental welding processes were used to calibrate and evaluate this simulation model as well as to identify the location of hot crack formation during the solidification phase. The developed two-staged numerical model is capable of calculating the temperature distribution for close-edge laser welding in first stage and determine the resultant stress and strain fields in second stage.
A criterion for the initiation of hot cracks could be defined based on this expertise. The criterion implies that positive strain combined with positive stress and multidirectional solidification conditions are responsible for hot crack formation.
Temporal analyses of the welding process with respect to melt pool volume, solidifying volume and maximum edge temperature led to the finding that there are three different stages of the close-edge welding process: The first phase is the starting stage, where the temperature field distribution develops, the volume of the melt rises as well as the maximum temperature at the edge. A quasi constant stage is reached after about 0,2 s, where a stationary temperature distribution is developed and no volume changes of the melt pool can be noticed. The third stage can be recognized after turning off the heat source, i.e. the laser power. Here a linear decrease of the melt pool size occurs and the temperature gradients start to flatten.
According to the numerically calculated welding conditions a hot cracking criterion was developed as follows: Multiplying the average strain and stress at the solidifying solidus-area with the quotient of the solidification volume and the melt volume gives a measure for sensitivity of hot cracking.

In terms of time-dependent structural changes, it is shown that minor strain and stress on the solidifying melt pool occur within the starting phase of welding. The timedependent behaviour of strain and stress in the starting phase of the welding process leads to a low hot cracking affinity and increases with further processing time until saturation occurs leading to a constantly high cracking sensitivity. With this knowledge two approaches to overcome hot cracking were developed.

The first approach investigated in this work uses a modulated laser power signal, where the two regimes of heat-conduction welding and deep-penetration welding are run through, thus leading to a repeating utilization of the starting phase of the welding process. As experiments with sinusoidally shaped and pulsed laser power signals proved, centerline hot cracks can be prevented with this method. However, due to the repeating closure of the deep-penetration welding capillary, the likeliness of pore formation increases.

The second proposed approach uses the maximum length of the starting phase as welding step size. To overcome the problem of crater crack formation at the end of such a weld step, the consecutive step are spatially overlaid. In order to effectively avoid hot cracks, the time between the steps is of major influence and has to be sufficient to allow solidification and uniform spreading of the temperature distribution. Applying the step strategy to four weld steps with sufficient cooling time led to a continuous, crack-free weld of 60 mm length. These welds can be evaluated with established quality control procedures, such as tensile and bending tests. Experimental results prove that the tendency for hot cracking is reduced, which is confirmed by welding tests on specimen shapes with high crack sensitivity. The resultant welds show no centerline crack.

In order to increase the efficiency of the step-strategy, it can be used with remote scanner optics which allows fast position jumps of the laser beam. This enables an almost simultaneous processing of different welds within the scanning field.

A final comparison of the developed step-strategy to the conventional metallurgical approach to overcome hot cracking with additional filler wire reveals higher productivity, higher efficiency and higher flexibility.