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# Reduction of transverse hot cracks by means of compressive stresses during laser welding of high strength aluminum alloys with high feed rates

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## Abstract

Laser welding of high-strength aluminum alloys at high feed rates leads to transverse hot cracks. These cracks present a major challenge for electromobility applications, especially in the manufacturing of battery cases, as transverse hot cracks can lead to a leaky weld seam and potential component failure. To determine suitable strategies for the avoidance of transverse cracks, their formation was experimentally investigated and theoretically analyzed. A simulation of the temperature field and the fluid flow in the melt pool showed a decrease of the static pressure at the liquidus isotherm at high feed rates. The decrease of the static pressure in the melt pool impairs the liquid feeding between the solidifying grains and increases the risk of transverse hot cracking. To balance this pressure drop in the melt, a mechanic compressive stress was applied on the sample during welding. Such stresses are present in case of welding e.g., rollforming profiles. The resulting welds show a significant reduction of transverse cracks which highlights the potential of applying external mechanical compressive stress to reduce the formation of transverse hot cracks.

Keywords: Laser Beam Welding; Aluminum Alloys; Electromobility Applications; Transverse Hot Cracking; Compressive Stress

## 1. Introduction

Joining long sheets of high strength aluminium alloys is crucial for applications in the field of electromobility, e.g., in the manufacturing of battery trays or cooling plates. To enhance productivity and capitalize on the

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availability of high laser powers, laser beam welding with high feed rates is used as described by Sun et al., 2020. However, laser beam welding of high strength aluminum alloys at high feed rates can lead to the formation of transverse hot cracks. Due to their solidification path, high-strength aluminum alloys have an increased susceptibility to hot cracking, as described by Weller et al., 2020. In current electromobility applications, transverse hot cracks pose a new challenge because they lead to a leaky joint and, in the worst case, to component failure.

According to the model of Rappaz et al., 1999, hot cracks form due to the separation of liquid melt between the grain boundaries due to thermomechanical deformations and solidification shrinkage. If the liquid feeding with melt into the area of solidifying grains is not sufficient, a hot crack will form, as described by criterion of Rappaz et al., 1999. Hu and Richardson, 2006 described the effect of the thermal history on the formation of transverse hot cracks. They conclude that a high heat input and a high feed rate increase the risk of transverse cracking. The results of Hagenlocher et al., 2019 showed that the hot cracking sensitivity of a weld can be reduced by welding with an increased depth-specific line energy.

To determine further mechanisms that lead to transverse cracks at high feed rates, a two-dimensional simulation of the temperature field and the fluid flow was performed with the model of Wagner et al., 2021. The results of this simulation will be discussed in the presentation. The simulation showed a critical point with a low static pressure at the widest point of the melt pool. According to the model of Rappaz et al., 1999, a low static pressure results in a lack of liquid feeding with melt between the already solidified oriented dendritic grains. This increases the risk of transverse cracking.

To avoid transverse cracking, there is a need to balance this pressure drop. Our experimentally investigated approach was to increase the static pressure in the melt pool by applying external compressive stress during welding.

## 2. Method

Fig. 1 depicts a sketch of the experimental setup, which is described in detail in Hagenlocher et al., 2020. As a sample we used the aluminum alloy S650 T4 from Novelis with a thickness of 2 mm thick and a width of 90 mm. To apply external compressive stress on the weld, the sample was clamped in a compression test rig.

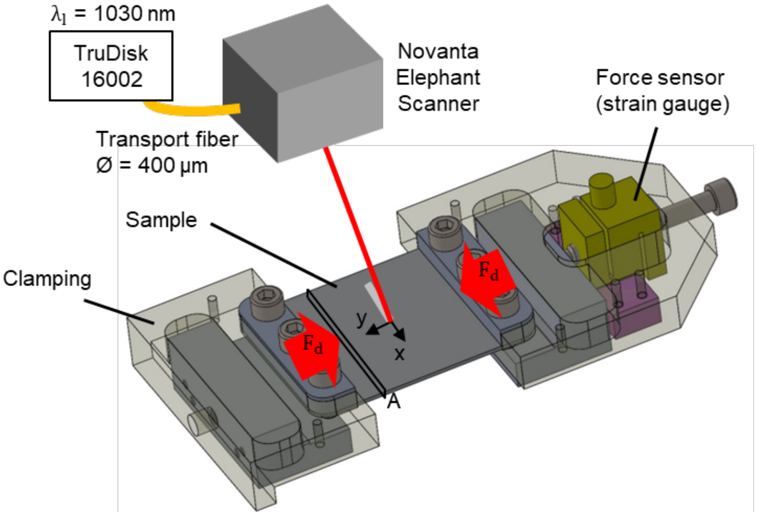

Fig. 1. Experimental setup to apply external compressive stress during welding.

The clamping device (light grey) includes a force sensor (yellow) that enables a setting of a uniaxial static compression of the sample (red arrows in Fig. 1). This causes a uniaxial compressive stress in y-direction that is applied before the welding process. The compressive stress in the sample can be calculated by dividing the measured compressive force with the constant cross-sectional area of the sample A = 180 mm$^2$. When welding in x-direction (see Fig. 1) a compressive stress transverse to the direction of the weld can be applied. If the welding direction is in y-direction, the compressive stress can be applied in the longitudinal direction.

A TruDisk 16002 laser from TRUMPF was used as a laser beam source, which yields a beam with a wavelength of $\lambda_l$ = 1030 nm. The laser beam was guided with a fiber with a core diameter of 400 µm. To focus and move the laser beam on the sample, a Fiber Elephant scanner system from Novanta Photonics with a magnification factor of 2.08 was used. This configuration results in a focal diameter of 832 µm on the surface of the sample and a Rayleigh length of 8.65 mm.

To investigate the influence of compressive stress on the formation of transverse cracks, two different welding parameters were investigated. The laser power was adjusted to receive fully penetrated welds. The laser power was set to 6.25 kW at a feed rate of 6 m/min and 14.25 kW at a feed rate of 17 m/min.

## 3. Results

Fig. 2b shows a horizontal section of the weld seam at a feed rate of 17 m/min when the sample is clamped in longitudinal direction ($\sigma_l$, welding in y-direction) and no external mechanical compressive stress is applied during welding. The force sensor and the clamping device did not press on the sample in this configuration. In the horizontal section of the weld seam several transverse cracks can be seen. Transverse cracks are initiated between the oriented dendritic grains and propagate from the edge of the weld seam to the centre and sometimes through the area with equiaxed dendritic grains.

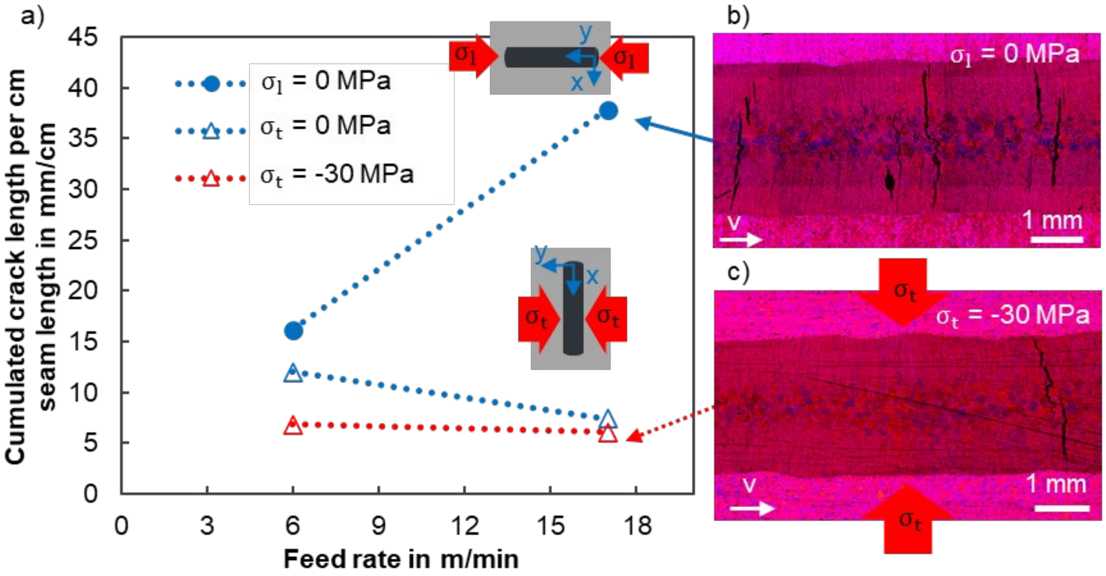

Fig. 2. (a) Cumulated crack length as a function of the feed rate and different clamping configurations with different compressive stresses; (b) Horizontal section of the weld seam at a feed rate of 17 m/min with no compressive stress and longitudinal clamping; (c) Horizontal section of the weld seam at a feed rate of 17 m/min with a transverse compressive stress of -30 MPa.

To quantify the crack susceptibility with one value, the lengths of the cracks were cumulated and related to the considered seam length. Fig. 2a shows the cumulated crack length as a function of the feed rate at different clamping configurations. The data points with a circle represent the cumulated crack length with a longitudinal clamping ($\sigma_l$, welding in y-direction), the data points with a triangle a transverse clamping ($\sigma_t$, welding in x-direction). The height of the compressive stress at the beginning of the welding process is displayed with different colours (blue: no external compressive stress, red: -30 MPa compressive stress).

With a longitudinal clamping and no external compressive stress (blue curve with circles) and a feed rate of 6 m/min the cumulated crack length has a value of 16 mm/cm seam length. At a higher feed rate of 17 m/min the cumulated crack length with 37 mm/cm seam length is more than twice as high than at a feed rate of 6 m/min. The number and the length of transverse cracks increases with higher feed rates.

A clamping of the sample in transverse direction and no additional compressive stress (blue triangles) leads to a reduction of transverse cracks for both investigated feed rates. Especially at a feed rate of 17 m/min the cumulated crack length is reduced by a factor of four compared to the weld seam without a transverse clamping. With a higher value of the applied transverse compressive stress of -30 MPa (red triangles) the cumulated crack length is further reduced at both feed rates. The horizontal section of the corresponding weld seam at a feed rate of 17 m/min is displayed in Fig. 2c. In the horizontal section one transverse crack can be seen. There is a significant reduction of transverse cracks with the application of transverse compressive stress, but no complete avoidance with the used setup.

## 4. Summary

As hot cracking is a considerable challenge in laser beam welding applications for electromobility, we investigated the influence of high feed rates on the formation of transverse hot cracks. The results show that the number of transverse hot cracks increases at higher feed rates. By applying a compressive stress transverse to the welding direction, the number of transverse hot cracks could be reduced by a factor of four compared to the reference with the same welding parameters without external compressive stress.

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