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Industrial applicability of reflection-assisted laser beam brazing of ZM-coated steel sheets

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Abstract

A major challenge in laser beam brazing of zinc-magnesium-coated (ZM) steel sheets is the uniform preheating of the substrate surface for achieving a stable wetting process. A process modification of the conventional laser beam brazing that addresses this requirement is the reflection-assisted laser beam brazing in laser leading configuration, which utilizes the laser reflections from the brazing wire onto the substrate material for preheating and wire melting with a single laser beam. In this study the industrial applicability of this process variant is addressed by analyzing the process parameters as well as the required position tolerance limits for continuous and uniform seams.

The results showed the suitability of a laser beam brazing process in laser leading configuration for ZM-coated steel sheets. Process velocities of 6 m/min were possible. Regarding the process tolerances it has been shown that flange joints with a gap width of up to 100 µm and lateral displacements of the TCP of up to 400 µm were joinable. The brazing seams showed a higher tensile shear strength than the substrate material.

Keywords: Laser brazing, Zinc-magnesium-coated steel, Reflection-assisted laser brazing

1 Introduction

Zinc-magnesium (ZM)-coated steel sheets, e.g. used in car body construction for automotive production, offer higher corrosion resistance than conventionally hot-dip galvanized steel sheets [1]. To connect this coated body parts, especially in areas that lie in the field of view of the customer, laser beam brazing in flanged joint configuration with copper based brazing material is widely applied [2]. ZM-coated steel sheets have higher demands on the joining process regarding a complete wetting inside of the flange joint area towards the conventionally used brazing materials, as shown by Wachsmuth et al. [3].

An approach to improve the wetting process is the preheating of the substrate surface [4]. In the conventionally used laser brazing processes with one laser beam in wire leading configuration the preheating is realized using a laser beam diameter bigger than the wire diameter. Nonetheless, the brazing wire is shadowing the substrate surface in front of the wire and the process zone respectively, limiting the area of direct preheating [5]. A possibility to improve the preheating is a laser brazing process in laser leading configuration as shown by Mittelstädt et. al. [5]. The brazing material and the laser beam axis are positioned with an inclination in process movement direction towards the surface normal of the substrate surface whereby the angle of the beam axis was bigger than that of the brazing material (cf. Fig. 1). The laser beam is thus positioned in leading direction, melting the brazing material from the bottom side. Due to the positioning of the wire and laser beam axis the reflected laser beam from the brazing material is partially reflected onto the substrate surface in front of the brazing material [6]. The joining zone in front of the brazing material is therefore directly preheated by the laser reflection. This enhances the preheating in comparison to the conventional process in wire leading configuration where the area in front of the wire is shadowed by the brazing wire.

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With regard to industrial applicability, robot-based laser brazing requires compliance with geometric tolerance limits such as joint gaps and offset between the joint and the tool center point (TCP) of the brazing optic. Variations of the geometrical arrangement for example can result from insufficient clamping, deformations of the substrate material before and during the process and inaccuracies in the process movement. However, these tolerance limits for the brazing process are currently not known.

In this study, the process limits regarding the combination of process velocity, wire feed rate and laser power were investigated for brazing of ZM-coated steel sheets. Regarding an industrial application of the joining process the tolance limits of the process towards variations of the geometrical arrangement such as joint gaps and TCP-offsets are examined.

2 Experimental setup

For the joining process a prototype brazing optic based on the concept of a conventionally used laser brazing optics ALO4 (Scansonic MI GmbH) was applied [6]. As presented in Fig. 1 the laser beam was positioned in leading position. The wire nozzle and laser beam axis were positioned with an angle of 10° and 30° respectively to the substrates surface normal in process movement direction. The optics was used in combination with a Trumpf TruDisk 12002 disk laser operating at a wavelength of 1030 nm and a spot diameter of 2.4 mm on the substrate surface. CuSi3Mn1 with a diameter of 1.2 mm was used as brazing material and the ZM-coated steel DX56D+100 ZM with a thickness of 0.8 mm served as substrate material. The brazing wire was transported using a DINSE DIX WD 300 wire transporting system. The experiments were carried out using flanged brazing joints with a bending angle of 90° and bending radii of 1.6 mm and 2.0 mm. For every parameter set a minimum of 3 samples was brazed.

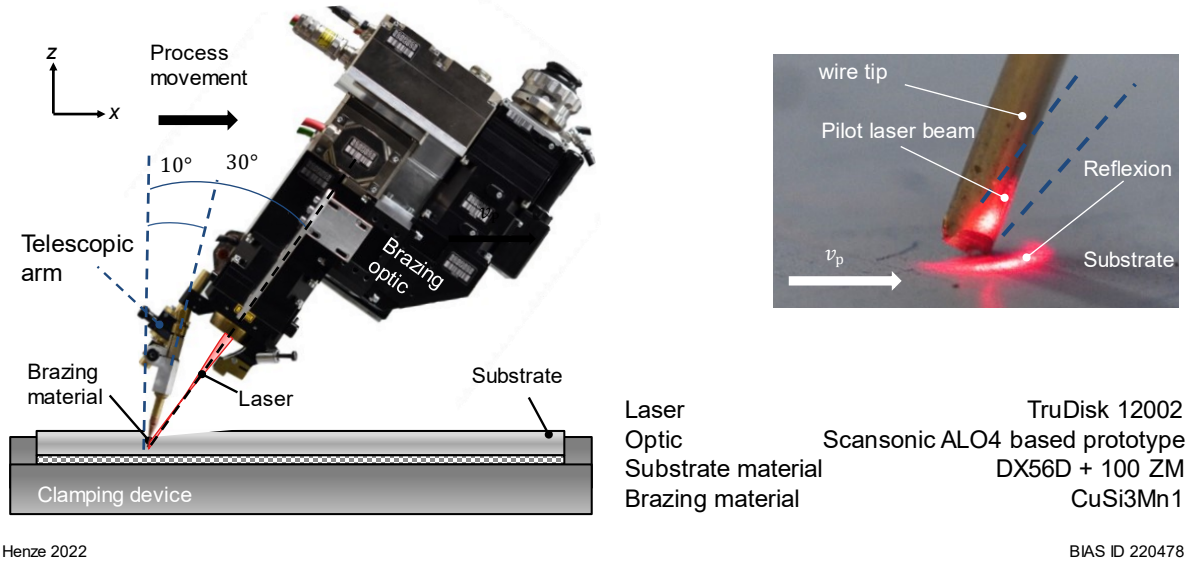


Fig. 1: Process setup and material

During the experiments suitable process parameter ranges were investigated. Therefore, the relevant process parameters e.g., laser power, wire feed rate and the process velocity, as well as the geometrical arrangement gap width and lateral offset of the TCP were varied. The local amount of melted wire depends on the ratio of the process velocity to the wire feeding rate. Therefore, the wire feeding rate was represented using the wire factor calculated with equation 1, where v_{wire} denotes the wire feeding velocity and $v_{process}$ the process velocity. The continuous complete melting of the wire in the tool center point (TCP) requires a certain amount of energy per unit length of the brazing wire. This energy is characterized by the gross energy for melting further denoted as E_{wire} as shown in equation 2. The applied laser power P_L is adjusted depending on the process velocity and the wire factor to keep the gross energy for melting in a certain range that was proven to ensure a stable wire melting in preceding studies. Therefore, instead of investigating the process window with respect to the laser power, the gross energy for melting was considered. In general, the gross melting energy depends on further parameters such as the wire diameter and the ratio between the wire diameter and the spot diameter. As those parameters were kept constant throughout the investigations presented in this study the equation for the gross melting energy can be simplified as shown in equation 2. Using these derived parameters

instead of the original process parameter enabled a comparison between the results of different parameter fields.

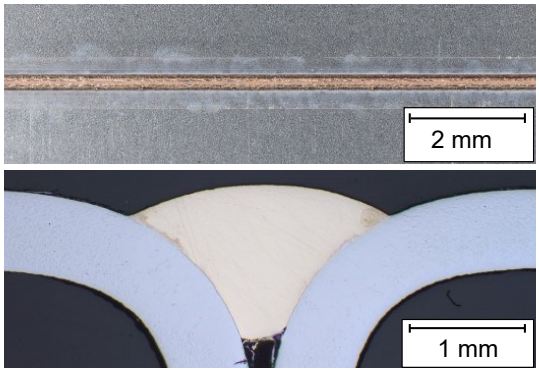
$$D = \frac{v_{wire}}{v_{process}} \tag{1}$$

$$E_{wire} = \frac{P_L}{v_{process} \cdot D} \tag{2}$$

The resulting brazing seams were evaluated based on the visual seam quality which is an indicator for a successful brazing process and important for the industrial applicability in the automotive production. Homogenous seams with continuous connectivity on both sides of the joint without inaccuracies on top of the surface or on the seam edge, were considered as seams without defect (green dots, e.g. Fig. 3) and therefore applicable seams. The joint quality of the applicable seams was measured using tensile shear strength tests with the tensile testing machine Zwick Roell Z250. The test specimens for the tensile shear strength tests were cut to a width of 45 mm by eroding before testing. The influence of the process velocity and the gross melting energy on the wetting behavior of the defect free seams was evaluated based on metallographic cross sections. Thereby the wetting length and depth were measured as indicator for the wetting quality.

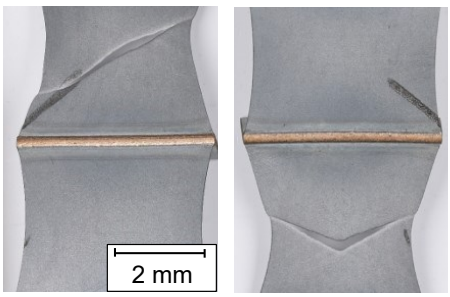
3 Results and discussion

The experiments showed that it is possible to join the ZM-coated steel in flange joint configuration using CuSi3Mn1 as brazing material in a laser brazing process with laser leading configuration. Fig. 2 shows an example for a brazing sample with an according cross section. The seam appearance was homogenous without irritations. The cross sections showed a steady connection of the brazing material with the substrate material without melting the latter.



Results of the tensile shear tests

Force at breaking	9275 N	9054 N



Laser	TruDisk 12002	Spot diameter	2.4 mm
Substrate material	DX56D + 100 ZM	Process velocity	3 m/min
Bending angle (substrate)	90°	Gross melting energy	34.5 J/mm
Bending radius (substrate)	1.6 mm	Wire factor	1.25
Brazing material	CuSi3Mn1 (ø 1.2 mm)	Tensile test machine	Zwick Roell Z250

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Fig. 2: Example for a brazing sample with the associated cross section and results of the shear strength test

Starting from the realization of a successful brazing process the boundaries of the process were evaluated. The investigations focused especially on the process velocity and the gross melting energy. Fig. 3 shows the dependance of the seam appearance on the process velocity and gross melting energy for flange joints with a bending radius of 1.6 mm. The samples with a bending radius of 2.0 mm showed a similar process window. The process window was limited due to significant defects such as insufficient wetting or balling (red dots) or an increased heat influence on the substrate material (yellow dots). The dots in the diagram represent the number of samples without and with defects for every parameter set. Small gross melting energies resulted in significant defects of the seam due to an insufficient preheating of the substrate material. High gross melting energies increased the intensity of the reflected laser beam on the substrate material which resulted in higher preheating of the substrate material up to an undesirable heat influence. A gross melting energy between 30 J/mm and 40 J/mm resulted in seams without defects or melting of the substrate material. Using a constant gross melting energy of 34.5 J/mm, small process velocities resulted in significant defects as insufficient wetting. Process velocities of at least 2 m/min were necessary. Higher process velocities of up to 6 m/min resulted in seams without defects for gross melting energies between 30 J/mm and 40 J/mm. The process showed a

similar tolerance towards variations of the gross melting energy for process velocities from 2 m/min to 6 m/min.

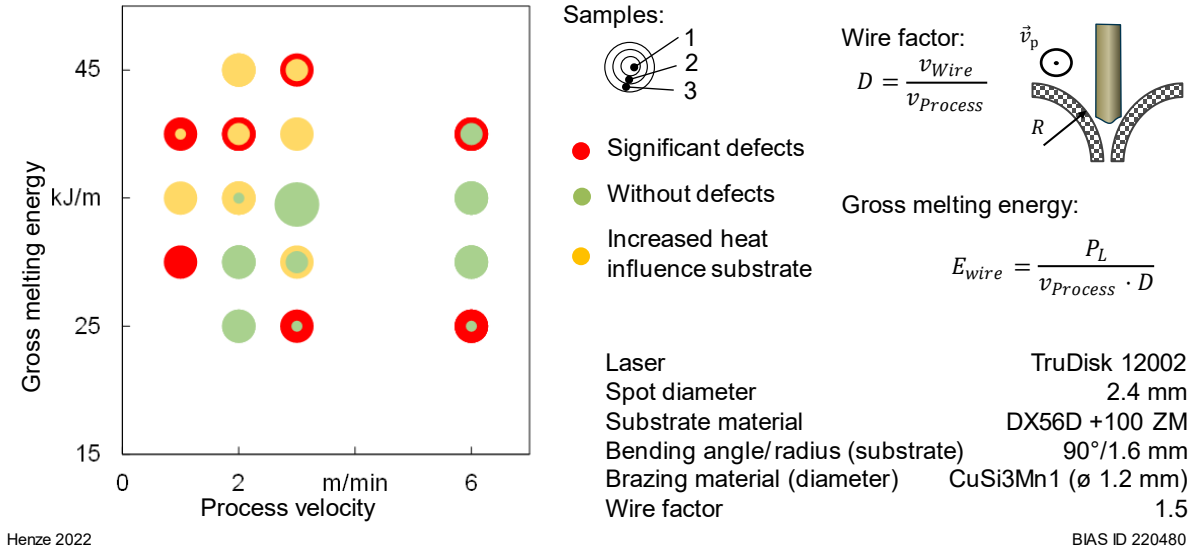

Fig. 3: Influence of the process velocity and specific gross energy for melting on the seam quality in laser brazing in laser leading configuration

To evaluate the influence of the process parameters on the wetting behavior the wetting length and depth were measured using microsections of the samples without visible surface defects. Three samples per parameter combination were examined. Both measurands were measured on the left and right side of each sample and the average value was calculated. Fig. 4 shows the results. The wetting length and depth increased with increasing gross melting energy and process velocity.

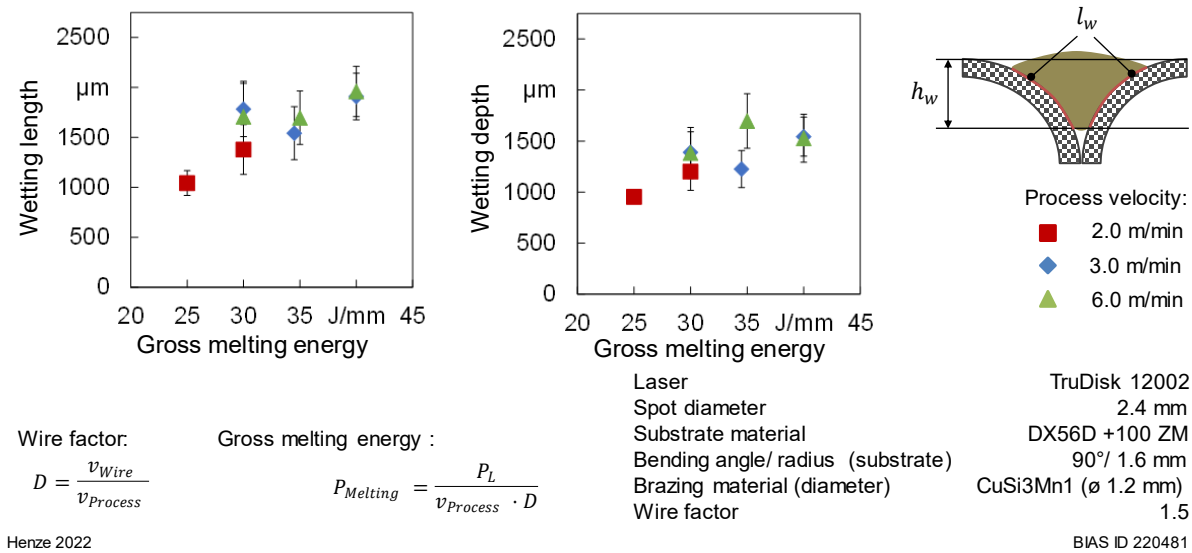

Fig. 4: Measurement of the wetting length and width as a function of the gross melting energy and process velocity

For the investigation of the influence of the joint gap and the lateral displacement a process velocity of 3 m/min and a gross melting energy of 34.5 J/mm were applied based on the previously determined process windows. The results were evaluated regarding the visual seam quality. Fig. 5 shows the results of the variation of the joint gap for flange joints with a bending angle of 90° and a bending radius of 1.6 mm. . The samples brazed with the smallest used wire factor of 1 (process velocity = wire velocity) had significant defects for all tested gap widths. This could be related to the small amount of melted brazing material or an insufficient preheating. For the smallest gap width of 0 µm and therefore the "zero"-gap a wire factor of 1.25 was sufficient to join the substrate materials. For higher gap widths the process window was shifted to higher wire factors due to the higher gap bridgeability when feeding increased amounts of melted brazing material to the joint interface (accompanied by a higher preheating). Gap widths of up to 100 µm were joinable. The number of samples with

seam defects increased with the gap width which was associated with a smaller process stability at higher gap widths.

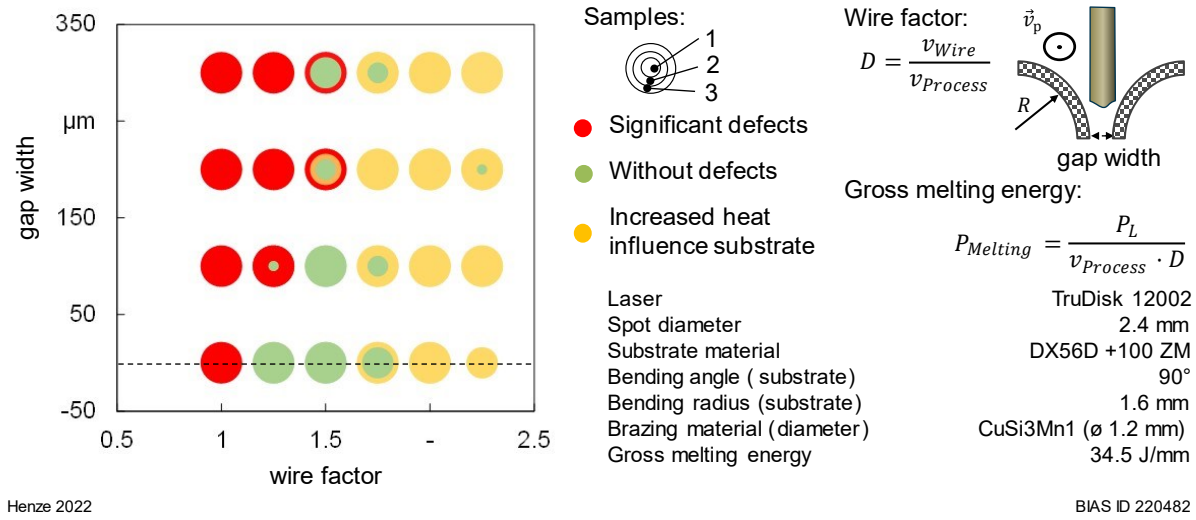

Fig. 5: Influence of the gap width and wire factor onto the visual seam quality

Fig. 6 shows the influence of the lateral offset of the TCP on the visual seam quality. The results show a dependence on the bending radius of the substrate material. For both bending radii tested, lateral offsets of up to 400 µm were allowable. Using smaller bending radii decreased the influence of the lateral offset.

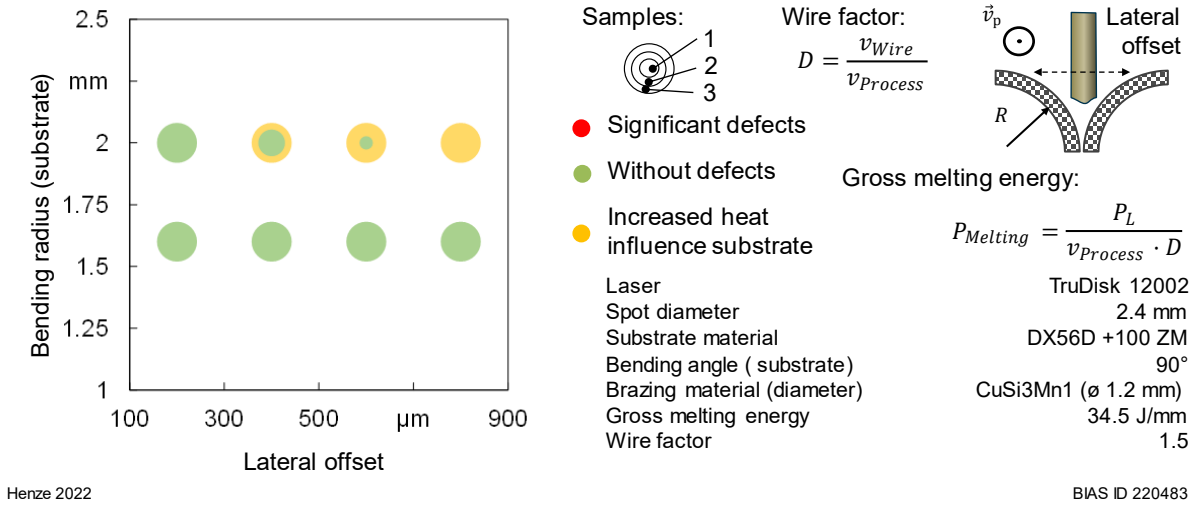

Fig. 6: Influence of the lateral offset depending on the bending radius of the substrate material onto the visual seam quality

The samples of the previously presented results for seams without defects were further investigated in tensile shear tests. The measured tensile shear force at breaking during the tensile shear strength tests for all tested process parameters was mainly between 9,000 N and 10,000 N. The samples broke in the substrate material, or the suspected heat affected zone of the substrate material or as a combination of both. Fig. 2 shows examples for tensile shear strength samples with breaking in the substrate material (right sample) and combined breaking initiated in the suspected heat affected zone of the reflected laser beam on the substrate material (left sample). The measured tensile shear strength was therefore that of the substrate material. The strength of the seam is higher. An influence of the tested process parameter on the tensile shear strength could therefore not be evaluated.

4 Summary

The investigation demonstrated the ability to join ZM-coated steel sheets in flange joint configuration with CuSi3Mn1 as brazing material using a laser brazing process in laser leading configuration without wetting defects. Thereby, process velocities of up to 6 m/min enabled defect free brazing seams. The tolerances of the joining process towards variations of the geometrical arrangement were identified. The process had a tolerance

towards joint gaps of up to 100 µm and towards a lateral displacement of the TCP of up to 400 µm. The tensile shear strength of the brazing seam was higher than the tensile shear strength of the used substrate material.

Acknowledgements

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References

[1] Volovitch P, Allely C, Ogle K (2009) Understanding corrosion via corrosion product characterization: I. Case study of the role of Mg alloying in Zn–Mg coating on steel. Corrosion Science 51:1251–1262. https://doi.org/10.1016/j.corsci.2009.03.005

[2] Koltsov A, Bailly N, Cretteur L (2010) Wetting and laser brazing of Zn-coated steel products by Cu–Si filler metal. J Mater Sci 45:2118–2125. https://doi.org/10.1007/s10853-009-3949-y

[3] Wachsmuth S, Nothdurft S, Reimann W et al. (2019) Laser brazing of zinc-aluminum-magnesium coated steel–influence of the joint geometry. In: Reisgen U, Zäh M, Schmidt MF et al. (eds) Proceedings of Lasers in Manufacturing Conference 2019: LiM 2019

[4] Gatzen M, Radel T, Thomy C et al. (2016) Wetting and solidification characteristics of aluminium on zinc coated steel in laser welding and brazing. Journal of Materials Processing Technology 238:352–360. https://doi.org/10.1016/j.jmatprotec.2016.07.026

[5] Mittelstädt C, Seefeld T, Vollertsen F (2016) Laser beam brazing of hot-dip galvanized thin sheet steel in laser leading process configuration. In: Laser Institute of America (ed) International Congress on Applications of Lasers & Electro-Optics. Laser Institute of America, p 1802

[6] Scansonic MI GmbH (2022) ALO4 – Scansonic | Bearbeitungsoptiken für das Laserschweißen, Laserlöten, Laserhärten, Laserschneiden. https://www.scansonic.de/products/alo4/. Accessed 15 Aug 2022