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Challenges and solutions for copper processing with high brightness fiber lasers for e-mobility applications

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Abstract

Components and materials in the automotive industry are changing with the increasing demand for electric vehicles. The use of copper in engines and in electric power transmission lines leads to new challenges in processing high reflective materials in high volume. The lack of absorption of NIR lasers together with other physical properties of Copper and Copper alloys caused in the past inefficient and instable welding processes. With the availability of high brightness and high power fiber lasers these issues can be overcome by very high power density. This leads to an immediate melting and creation of a keyhole which increases the absorption compared to the solid material. With adapted process technologies such as high dynamic beam deflection the welding process can get stabilized and spatter and blowholes can be avoided or reduced to a minimum. This paper gives an overview on the process chain of Copper processing from cutting with high brightness fiber lasers to conditioning of Copper wire with high energy pulsed lasers to a stable and reliably welding process.

Keywords: Joining; surface treatment; Copper; dynamic beam forming; high brightness lasers;

1. Introduction

Processing of Copper by means of Lasers has a very high potential in future applications for e-mobility and electrical power storage and transmission. However, the wavelength of solid state lasers and the process itself have shown in the past that there are issues in process stability caused by lack of absorption and the physical properties of the material.

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The absorption of laser radiation on solid Copper at the beginning of the process is very poor for laser in the near-infrared wavelength range. The solution is either the use of shorter wavelengths for better absorption such as green lasers a 532 nm, or a very fast passing of the solid state by an immediate melting and evaporation of the material with high power density. While green lasers are either not available yet at the high required power level for deep penetration welding or they are not industrially proven yet, single mode and low mode near infrared (NIR) fiber lasers are available and widespread in the market for years. The power density of a 1 KW single mode laser can reach up to 1 MW/cm^2. With this high power density the lack of absorption (4% in the solid state) can be overcome in a very short time and the absorption of the molten or evaporated Copper increases up to more than 60%, see table 1.

Table 1. Absorption of Copper for NIR Lasers

State	Absorption (%)
Solid	4
Fluid	10
Keyhole	> 60

In Laser cutting we see today that due to the change from CO_2 Lasers to high power solid state lasers – a reduction of the wavelength - the bandwidth of materials to be processed increased enormously. High reflective materials such as Aluminum, Copper and Copper alloys can now be processed without restrictions. (Bild oder schneiddiagram)

In welding we face beside the absorption also other issues. One is reduced weld quality by spatter and blowholes caused by the viscosity of the melt pool. This was discussed and described earlier e.g. by Liebl et al., 2014 and one known solution to avoid this is welding at high speed. But, high speed consequently means a reduction of the penetration depth by reduced energy per unit length. This can be compensated either with increased laser power or the wobble technique, Walter et. Al, 2014. Wobble technique means that the fast movement to stabilize the process is generated by a fast beam deflection by means of galvo-driven scan heads, but at the same time a relatively slow welding movement creates the weld seam and maintains the welding depth. This combination of movements results in high quality weld seams with sufficient penetration depth in a stable keyhole welding process, Fig. 1.

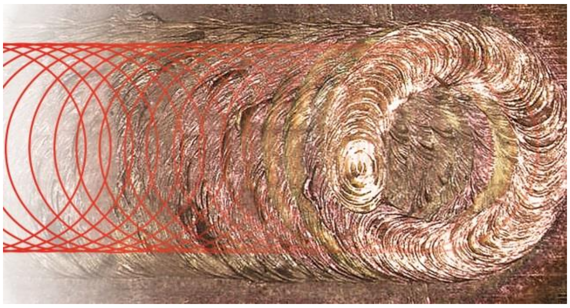

Fig. 1. Wobbled welding of Cu

2. Experimental

The experimental work for Laser welding was carried out with high power single mode and low mode fiber lasers. These lasers can create spot sizes of 20 – 50µm on the workpiece enabling fast coupling of the beam. The wobble movement can be either created by galvo-driven scan heads or with so called wobbling heads which combine the advantages of scan heads with those of standard welding heads: High dynamic deflection and positioning and at the same time the use of standard focusing units which can withstand higher power densities with lower focal shift compared to F-Theta lenses. A compensation of the focus position in beam direction is not required as the deflection angles are very limited. The heads can operate pre-programed simple figures such as lines or circles or figures of eight or with external controllers more complex shapes. For most Copper applications the circular movement shows best results and allows 2D movements without dependencies on the direction. These heads are available for power levels up to 12 kW, Fig. 2.

Fig. 2. IPG Photonics Wobble Head for high dynamic beam forming

A variation of frequency and wobble amplitude showed that the frequency range of 100 to 600Hz gives the best results. For large amplitudes the required circular speed to stabilize a process can be achieved already at low frequency while for small diameters higher frequencies are required. A too high circular speed (large amplitude, high frequency) results in an instable process again. Fig. 3. shows the cross sections of welds at constant frequency and welding speed, but different amplitudes. It can be seen that the amplitude defines the cross section of the weld. Small amplitudes result in V und U-shaped welds while large amplitudes create square or rectangular shaped cross sections with a very regular depth over the complete width. These shaped welds allow overlap welding with defined penetration depth and large connected areas. Especially for battery applications this results in large conducting cross sections with low heat input and controlled welding depth. When amplitude is much larger than spot size the melt pool solidifies already after a short length on the circle and forms a weld seam consisting of overlapping rings, Fig. 1. Smaller amplitudes develop a common meld pool over the complete width. In both cases a stabilization of the weld is given.

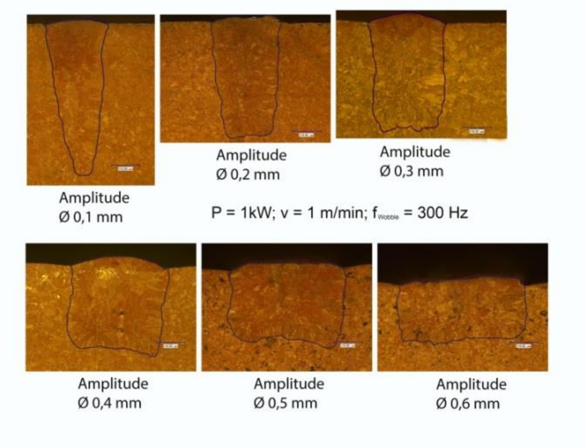

Fig. 3. Weld cross section for different wobble amplitudes

The same technology can be applied to pulsed welding. While at continuous wave welding the absorption hurdle has to be overcome just once, in pulsed welding this has to happen for each pulse. With increased absorption after melting and evaporation the melt pool starts to overheat, which typically results in spatters. The only way to avoid this in a static process is pulse shaping with sophisticated individual pulses described by Dürr, 2008. With the wobble technique we can create a continuous and dynamic weld during a single pulse. This results in stable spot welds by circular beam movement. Fig. 4 shows stills from a high speed video where a certain number of overlapping pulses creates a high quality linear pulsed weld seam.

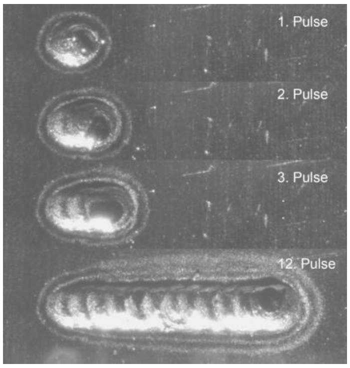

Fig. 4. Development of a pulsed weld seam with dynamic pulses

2.1. Example of an for E-mobility application

Many E-mobility applications require a welding of flat wire ends to one conductor. These rectangular shaped wires are often used for compact windings in motors or generators. The wires are typically coated with insulating enamel which has to be removed before welding. A fast and residue-free de-coating and cleaning of the wire is required before welding as all remaining residues lead to pores in the weld and so reduce the conducting area. Cleaning and ablating at high rates can be done with high energy pulsed Lasers.

The tests were carried out with a laser of the type YLP-HP-100-70-10-1000. This laser delivers a pulse energy of up to E= 100mJ at a pulse duration of t= 70ns. For high rate processing this Laser is optimized with a square shaped fiber. This allows a reduced overlap and a more uniform ablation. In a multi pass process it is possible to de-coat areas with a rate up to 300 mm^2/s.

After de-coating typically two or three flat wires get stacked and welded from the front end. For this application a static wobble weld shows best results. This means the wobble welding head does not move while the beam is deflected high dynamical over the front end and allows melting of the ends to a ball-shaped connection. Amplitude, interaction time and power regime allows to define the size of the "ball" created by the molten wire ends. Fig. 5 show a wire after cleaning (a) and the cross section of the weld (b) of three 1.5mm thickness wires. It can be seen that the fusion zone is larger the cross section of a single wire and the weld is free of pores.

(a) (b)

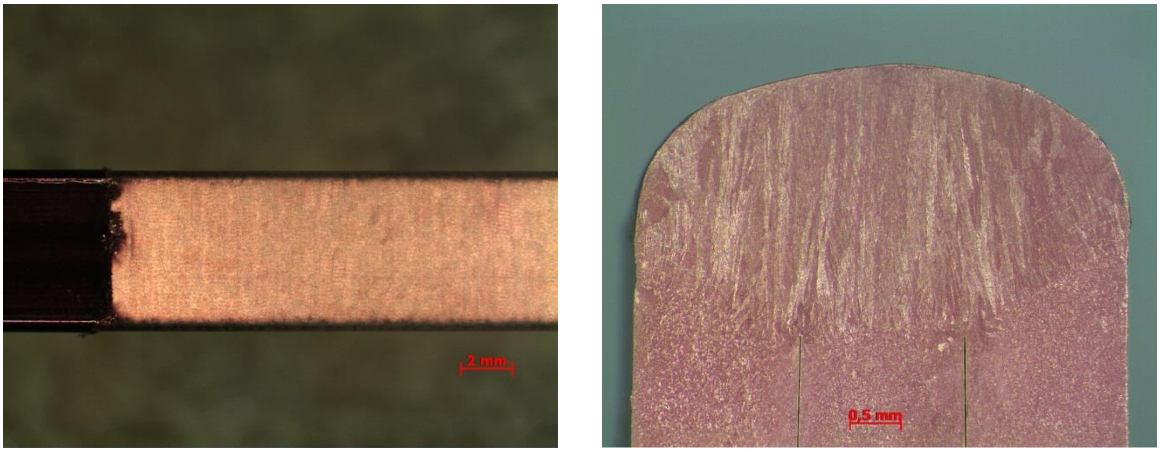

Fig. 5. (a) Laser de-coated wire surface; (b) Cross section of wire end weld

3. Summary

High brightness fiber laser allow stable and efficient processing of Copper. Cutting of Copper is today already a standard for flatbed cutting systems. For welding applications the high power density of fiber lasers allows stable welding at high speed. With the wobble technique this high welding speed can be maintained on a circular path, which enables high quality welds at moderate welding speed with deep penetration.

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