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Conditioning of copper material surfaces increasing the efficiency of continuous wave laser microwelding

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ABSTRACT

Major challenges in the welding of copper are high reflectivity for infrared wavelengths and insufficient reproducibility of the welds. Studies have shown that the surface conditioning of copper materials with pulsed green laser radiation stabilizes process conditions, as well as significantly increases absorption of pulsed infrared laser radiation. Experimental results are presented, which illustrate how advantages of this conditioning can be transferred to welding with continuous IR radiation. It is possible to significantly reduce the necessary IR laser power and to optimize the weld appearance. In this regard, the influence of inert gas and the conditioning parameters is analyzed.

Introduction

For several decades, the semiprecious metal copper has been, because of its very high thermal and electrical conductivity, an indispensable material in the field of power electronics and is being used in almost all electronic devices. Besides power semiconductors, lead frames and several other electrical contacts, copper materials are applicable in a variety of applications, such as plain and rolling bearings or in tube processing. To be able to maintain and to expand the own position in this industry, both the products and the production processes must be continuously improved. An important task for these production processes is the development of thermally stable copper contacts for electronic products. Given the high demands on these contacts, solder joints are no longer sufficient. Thus, it is foreseeable that the processes will be largely converted to welding processes. In this regard, the process of reliably joining copper and copper materials by laser radiation for the competitive industrial use will be further developed as part of the research work presented in this paper.

Laser welding of copper is particularly advantageous for applications when a contactless, very precise input of energy, a high temperature resistance and a high mechanical strength are required. In contrast to other metals, copper has properties that result in a reduced process safety and quality when welding with infrared (IR) laser radiation. For this reason, the use is mainly confined to non-automated, manual applications. One of these properties is that the absorption of a conventional 1 μm Laser, such as a Nd:YAG laser (1064 nm) is only about 4%, whereas a significantly higher absorption is presented in the visible spectral region. For example, the radiation of a frequency converted laser (532 nm) is absorbed with about 40%. Furthermore, the absorption of copper escalates by reaching the melting temperature, which negatively affects the controllability of the welding quality [1–3].

State-of-the-art

To increase the process reliability and the quality of the welding joints, currently approaches such as pulse shaping, real-time power control or the use of frequency-converted lasers are persecuted [4–6].

Due to the significant increase of the absorption, the use of frequency-converted lasers is the most promising method. In this context, a method for reliable pulse welding was developed [7]. Ulterior motive is to upgrade existing IR laser systems with low investment costs through a low-cost short-pulse module. The advantage of the increased absorption of a frequency converted, short-pulsed laser is utilized to achieve a surface conditioning and a uniform initiation of the pulse-welding process. This frequency-converted laser radiation conditions the surface, whereby the oxide layer thickness is increased, and reproducible starting conditions are created, then to be overlaid with the infrared laser

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beam for the welding process. For this combination of 527 nm and IR radiation, very high process reliability, as well as 20–40% energy savings could be demonstrated for spot welding [1,7].

By studies on the conditioned surface, an increase in roughness and the oxygen content could be detected with increasing pulse energy and overlap of the conditioning pulses (see Fig. 1). Besides the pulsed process, it is shown that the absorption rises with increasing conditioning pulse energy for continuous wave IR welding processes, i.e. with increasing roughness and oxygen content of the surface [8]. Based on these pulse welding results, research results for continuous wave welding are presented below.

Experimental setup and methods

For the experimental investigations of copper welding, a pre-pulse module is combined with a typical continuous wave IR laser. The pre-pulse module is an end-pumped, passively Q-switched solid state laser with subsequent frequency conversion. For the spatial superimposition of the two laser radiations and to generate weld seams, an experimental setup was developed (see Fig. 2). By expanding the green laser beam, a uniform distance to the focal plane is realized for both wavelengths. The positioning of the samples is done by a high-precision axis system with a maximum speed of 50 mm/s. To analyze the influence of the inert gas argon, while ensuring repeatable process conditions, the experiments are conducted in an open-top process chamber. The process can be monitored with an observing camera.

For surface conditioning, three different methods are used (see Fig. 3). The first method is the selective spot conditioning, *SC*, wherein a single spot weld is produced at the beginning of the weld seam by the described experimental setup. In this case, the conditioning and the welding process can be carried out in direct succession, using the same setup. The second method is the hatch conditioning, HC. Here, the samples are conditioned over a large area on an external station using a pulsed scanner system, leading to greater surface modifications. These modifications can be seen in the SEM images shown in Fig. 3. The HC increases both the oxide content, as well as the surface roughness depending on the energy and degree of overlap of the laser pulses [7]. The target is a higher absorption of the laser radiation. The third method, the onset conditioning method, *OC*, is similar to the *HC* method, except that only the beginning of the weld is conditioned. The laser specifications of the two conditioning lasers and the welding laser are given in Table 1. The hatch conditioning surfaces are produced with a pulse overlap of 95%. The pulse overlap, OL, is calculated by $\mathrm{OL} = 100(d_f - a_s)/d_f$ where d_f indicates the focus diameter and a_s indicates the distance of the lines.

The copper materials CuSn6 and Cu-OFE examined are 0.5 mm and 1 mm thick each. Investigations have shown that the surface quality (brushed/unbrushed) has no critical influence on the oxide content, the roughness, the surface topology and thus on the laser absorption after the surface conditioning [8]. Therefore, only rolled, unbrushed materials are considered. The material CuSn6 is typically used for stampings, connectors and contact springs. Cu-OFE is a high-purity copper with a copper content of ≥99.9%, where typical applications include coaxial cables and hollow conductors, underwater fibre optic cables, semiconductors, heat conductors and heatsinks. With 75 W/(mK) for CuSn6 and 394 W/(mK) for Cu-OFE, the conductivity differs heavily [9].

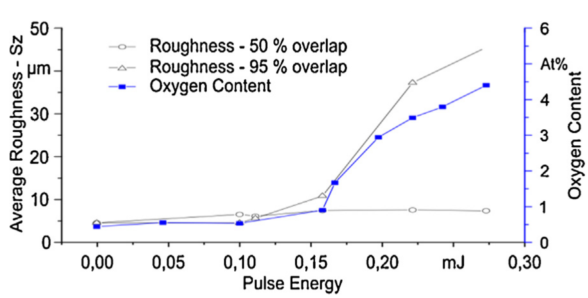

Fig. 1. Influence of the pulse energy to the oxide content and surface roughness of Cu-OFE.

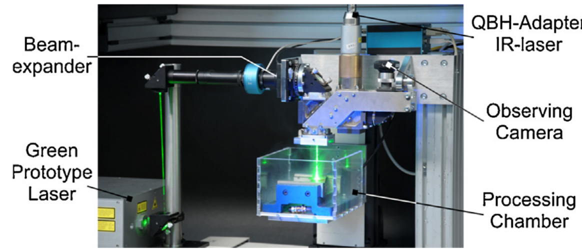

Fig. 2. Experimental setup – combined laser head.

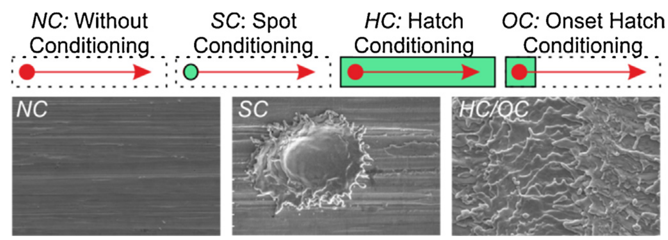

Fig. 3. Surface conditioning methods: process cycle and SEM images.

Table 1
Laser specifications.

Specification	neoLASE prototype	Rofin powerline E20	nLIGHTalta™
Wavelength	527 nm	532 nm	1080 nm
Operation mode	Pulsed	Pulsed	Continuous wave
Average power	200 mW	5.5 W	3100 W (max.)
Pulse energy	2 mJ	0.2 mJ	–
Pulse duration	5 ns	5.6 ns	–
Spot diameter	35 µm	50 µm	60 µm, 200 µm

Experimental results

First, the findings on bead-on-plate welds are presented. Next, these results are transferred to butt, and overlap welds. The study is carried out in an argon-rich environment (measured $O_2 \leq 1.5\%$), because preliminary investigations proved that cleaner welds occur and only marginally more energy is required under an inert gas atmosphere. The investigations are conducted at a maximum speed of 50 mm/s limited by the setup. The parameters tested are the laser power, the spot diameter, the thickness of the materials and the methods of surface preconditioning, carrying out three repetitions for each parameter. Hereinafter, the spot conditioning, *SC*, is not considered, since the investigations revealed that the influence is negligible compared to the hatch conditioning.

Bead-on-plate welds

The first investigations were carried out on bead-on-plate welds to determine the appropriate power levels required to weld the copper materials with different preconditioning methods. Fig. 4 shows the welding results on 0.5 mm thick Cu-OFE generated